



**United Nations
Environment
Programme**



Distr.
GENERAL

UNEP/CHW/OEWG/1/INF/6
25 March 2003

ENGLISH ONLY

OPEN-ENDED WORKING GROUP OF THE BASEL
CONVENTION ON THE CONTROL OF
TRANSBOUNDARY MOVEMENTS OF
HAZARDOUS WASTES AND
THEIR DISPOSAL

First session
Geneva, 28 April to 2 May 2003

Item 5 (d) of the provisional agenda*

**DRAFT TECHNICAL GUIDELINES ON THE ENVIRONMENTALLY SOUND
MANAGEMENT OF PERSISTENT ORGANIC POLLUTANTS AS WASTES**

Enclosed is the January 2003 version of the technical guidelines on the environmentally sound management of persistent organic pollutants as wastes. For reason of economy, pages 58-71 containing the "References Cited" and "Bibliography" are not included in this information document. However, delegates can refer to those pages in the meeting document as found in the Basel Convention website (<http://www.basel.int>).

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FOREWORD

These technical guidelines are principally meant to provide guidance to countries that are building their capacity to manage wastes consisting of, containing or contaminated with persistent organic pollutants (POPs) in an environmentally sound and efficient manner and to assist them in their development of detailed procedures for the management of these wastes. The guidelines pertain to POPs wastes generated and disposed of locally as well as such wastes imported as a result of transboundary movement, or arising from the treatment of imported wastes.

This document is to be considered in conjunction with the Technical Guidelines on Wastes Comprising or Containing PCBs, PCTs, and PBBs (Basel Convention Series/SBC No. 97/009) which was adopted by the second meeting of the Conference of the Parties in March 1994. In particular, special attention should be given to the national/domestic legal framework and the responsibilities of the competent authorities. These guidelines are intended to help countries in their efforts to ensure, as far as practicable, the environmentally sound management of the wastes subject to the Basel Convention within their national territory and are not intended to promote transboundary movements of such wastes.

EXECUTIVE SUMMARY

The primary purpose of this document is to provide technical guidelines on the environmentally sound management (ESM) of persistent organic pollutant (POPs) wastes in order to provide direction to the Parties and signatories of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (1989) and the Stockholm Convention on Persistent Organic Pollutants (2001) in implementing their obligations under these conventions.

POPs are very stable, carbon-based chemical compounds and mixtures. These pollutants are classified as 'persistent' because they are not degraded easily in the environment by physical, chemical or biological processes. The currently identified POPs are primarily pesticides, industrial products and by-products, of which 12 chemicals and/or groups of chemicals have been identified by the Stockholm Convention for reduction and, where feasible, ultimate elimination. These are aldrin, dieldrin, chlordane, toxaphene, mirex, endrin, heptachlor, hexachlorbenzene (HCB), polychlorinated biphenyls (PCBs), dichloro diphenyl trichloroethane (DDT), polychlorinated dibenzo-p-dioxins (PCDDs, 'dioxins') and polychlorinated dibenzo-p-furans (PCDFs, 'furans').

Article 6 of the Stockholm Convention concerning measures to reduce or eliminate releases from stockpiles and wastes left open a number of definitional issues. It required the Conference of the Parties to cooperate closely with the appropriate bodies of the Basel Convention in addressing these, in particular to establish appropriate levels of destruction and irreversible transformation for POPs wastes; to determine what they consider to be methods that constitute environmentally sound disposal; and to establish, as appropriate, the concentration levels that would define low POPs content. The Conference of Plenipotentiaries that adopted the Stockholm Convention in May 2001 also invited Basel Convention bodies to cooperate closely on these matters and to prepare technical guidelines on the environmentally sound management of persistent organic pollutants. The Conference of the Parties of the Basel Convention, at its fifth meeting in December 1999, had similarly called for the secretariat of the Basel Convention under the guidance of the Technical Working Group to provide technical and other guidance to the Stockholm Convention's interim governing body. Preparation of guidelines on POPs was included in the Technical Working Group's programme of work.

The technical guidelines produced in this document are intended to be generic. It is acknowledged that many developed countries have already implemented management systems/procedures that are specific to their circumstances, and may surpass the requirements specified in this document. The guidelines that have been recommended in this document should be considered as minimum requirements for the identification, storage, handling and disposal/destruction of POPs wastes.

Considering the various technologies available or under development for handling POPs wastes, it is important to distinguish between: (a) technologies that concentrate POPs in wastes so that the resulting pre-treated waste can be better subjected to a technology for destruction or irreversible transformation, (b) technologies that sequester the waste, and (c) technologies that actually achieve some measure of destruction or irreversible transformation. These guidelines consider the following technologies (not all of which are yet fully commercialized):

- **Technologies for destruction and/or irreversible transformation of POPs wastes**
 1. Incineration
 2. Gas-phase Chemical Reduction (Hydrogenation)
 3. Electrochemical Oxidation
 4. Molten Materials Treatment (molten metals or salts)
 5. Solvated Electron Processes
 6. Plasma Arc Processes
 7. Base-catalyzed Decomposition

- **Technologies for sequestration of POPs wastes**
 1. Engineered Landfills
 2. Long-term Storage
 3. Deep Well Injection
 4. In-situ Vitrification

- **Pre-treatment technologies for concentration of POPs wastes**
 1. Electro-osmosis
 2. Thermal Desorption
 3. Low Temperature Rinsing and Recovery of PCB Containing Materials

An assessment was carried out and criteria provided for determining environmentally sound disposal technologies. Based on the evaluation of various technologies and their capability to destroy POPs as well as considering the requirements of destruction under the Stockholm Convention, the following observations can be made:

- the necessary levels of destruction and irreversible transformation (“destruction efficiency” or “DE”) should be in the order of 99.999% + (based on 100% POPs content in the input stream) as some of the technologies commercially available or being tested have the capability of achieving this level of destruction;
- the technologies range from very simple to extremely complicated and expensive, and the amount of operator training required also varies from simple to extensive;
- the environmentally sound disposal of POPs wastes is a complex issue – encompassing the concept of both sustainability and environmental friendliness of the disposal method. At the heart of this concept is to ensure that the disposal method is acceptable technically and socially (short and long-term health and economic impacts);
- the economics of the disposal process itself can be a limitation for many countries; and
- infrastructure needs, e.g., appropriate regulatory framework, adequate monitoring capabilities, appropriately trained personnel, etc., may also be limitations for many countries.

[The determination of acceptably low levels of POPs (below which control is unnecessary) is a complex process. Because of the characteristics of many of the identified POPs there may be a risk to human health or the environment even at very low concentration. Therefore, the final outcome would always be an acceptable level with an acknowledgment that there is some residual risk. The methodology that might be adopted could be used to study the exposure pathways of the POPs in a specific scenario to a pre-assigned receptor through air, water or soil. The level of acceptable risk can then be back calculated to provide a concentration of the particular POPs in the medium.]

There is a need for setting up ground rules for establishing an acceptable level of POPs. These should be defined as low levels of POPs by the Technical Working Group (TWG) with regard to the acceptable level of lifetime risk, representative ecological receptors and potential pathways, and toxicological characteristics/criteria for acceptability.]

OR

[Greenpeace's suggestion:

There are far-reaching economic, ecologic and public health implications to the establishment of threshold concentrations of POPs in wastes for determining specific POPs-contaminated wastes fall within the purview of the Stockholm Convention or can be excluded from such consideration. Almost all the currently listed POPs have been classified as known, probable or human carcinogens. According to many authorities, there are no safe levels of exposure to carcinogens since exposure at any level may lead to cancer. Consequently, establishing concentrations of POPs in waste below which there is no requirement that the POPs are destroyed or reversibly transformed will be a complex and arduous process. There is a need for setting up ground rules for establishing threshold levels of POPs – the levels below which no treatment will be required.]

OR

[WCC's suggestion:

A more fruitful and generally acceptable approach to determining concentration levels of POPs that represent 'low POP content' in the context of Article 6 §1(d)(ii) of the Stockholm Convention may be to make use of the concept of 'best available techniques' (BAT) as is in any case required for Annex C substances under Article 5 of that Convention.]

1.0 BACKGROUND

POPs are very stable, carbon-based chemical compounds and mixtures. These pollutants are classified as 'persistent' because they are not degraded easily in the environment by physical, chemical or biological processes. The POPs identified by the Stockholm Convention include pesticides, industrial products and by-products.

The Conference of the Parties to the Basel Convention at its fifth meeting (COP5) in December 1999 extended the mandate in its decision V/26 of the Technical Working Group to undertake, inter alia, the preparation of technical guidelines on the environmentally sound management of POPs as wastes. While assessing the priorities, the Technical Working Group at its sixteenth session in April 2000 requested that the secretariat elaborate on the preparation of the technical guidelines on POPs as wastes.

At its seventeenth session in October 2000, the Technical Working Group considered the relationship between the Basel Convention and the proposed legally binding instruments on POPs. The Group decided to initiate the development of technical guidelines for environmentally sound management of POPs as wastes and requested that the secretariat prepare an outline, taking into consideration the discussions and outcome of the Intergovernmental Negotiating Committee (INC) on POPs, and extended an invitation to all appropriate bodies of the future POPs convention to contribute to the preparation of these guidelines.

The Technical Working Group, at its eighteenth session in June 2001 agreed to set up, under the chairmanship of Canada and Senegal, a small working group that would operate inter-sessionally to assist the secretariat in the preparation of the technical guidelines; Parties, United Nations Environment Programme (UNEP), the chemical industry and environmental non-governmental organizations (NGOs) are part of this group. The Technical Working Group defined the framework for the development of the technical guidelines and recognized the urgent need to begin drafting of the text of the technical guidelines.

The nineteenth session of the Technical Working Group in February 2002, was briefed by Canada on its plans to update the Basel Convention technical guidelines on wastes comprising or containing PCBs.

The Stockholm Convention on POPs, concluded in May 2001, identified a list of 12 POPs, for immediate action. These are categorized as follows:

- Annex A – (Elimination of production and use): aldrin, chlordane, dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), mirex, toxaphene and polychlorinated biphenyls (PCBs);
- Annex B – (Restriction of production and use): DDT; and
- Annex C – (Continuing minimization and, where feasible, ultimate elimination): polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF), HCB and PCBs produced as by products.

There is strong scientific evidence supporting that POPs are likely to cause significant adverse effects to human health, fish, biota and wildlife. POPs are problematic because of several intrinsic characteristics:

- persistence in the environment - they resist degradation through physical, chemical, or biological processes;
- semi-volatile - Substances with this property are subject to long-range transport and circulate globally via multiple cycles of evaporation, aerial transport and condensation in oceans and on surfaces. POPs released in one part of the world can travel to regions far from their source of origin. Through the “global distillation” process they preferentially end up in the high latitudes;
- low water solubility and high lipid (fat) solubility - substances with these properties bioaccumulate and bioconcentrate in fatty tissues of organisms and biomagnify in the food chain so that the major route of human exposure is through the consumption of fish and animal products. They may also be transmitted from a mother to a foetus across the placenta and to newborns through breast milk; and
- toxic - they have the potential to harm humans, wildlife and other organisms, in some cases at very low concentrations. Examples of toxic effects exhibited by various POPs include damage to the nervous system, reproductive disorders, disruption of the immune and the hormonal systems, and cancer.

In the early decades of the 20th century, POPs were virtually non-existent in the environment. However, there was a dramatic increase in the production and generation of POPs following World War II. Today, POPs have been detected in food supplies, especially fish, meat and dairy products, as well as in ecosystems, and in humans in most regions of the world. POPs have been measured in populations of humans and wildlife at concentrations near, or above, those known to cause harm.

Humans are generally exposed to POPs through their food supply, although workers and residents of communities near sources of POPs may also be exposed through inhalation and dermal contact. POPs exposures are often highly pronounced in peoples whose diets include large amounts of wild food and especially large amounts of fish, marine mammals or other aquatic foodstuffs, especially where such people inhabit high latitudes or colder regions such as the Northern Aboriginal People in the Arctic and sub-Arctic Regions.

With the evidence of long-range transport of POPs to regions where they have never been used or produced, and the consequent threats they pose to the global environment, the international community has through the Stockholm Convention called on Parties to prohibit or restrict the production and/or use of intentionally produced POPs and to take certain measures to reduce the total releases of by-product POPs with the goal of their continuing minimization and, where feasible, ultimate elimination.

Parties to the Stockholm Convention are required to develop appropriate strategies to identify, collect and destroy or dispose of POPs wastes, in accordance with Article 6 of the Stockholm Convention. The establishment of systematic and sustained programs with appropriate management control on an interim basis is a priority today.

2.0 OVERVIEW OF POPs

Eight of the Stockholm POPs are pesticides that are intentionally released into the environment. Spray drift, evaporation from plant, soil, water, and treated wood surfaces, surface water runoff, and percolation into groundwater are all pathways by which pesticides enter the environment.

The use and/or production of some of the most persistent and toxic pesticides, such as aldrin, dieldrin, chlordane, and toxaphene, have been banned or restricted in several countries. However, such measures are far from universal; in many countries, restrictions have been imposed only within the last few years. Differences in the use of POPs from country to country is evident, for example, in the case of DDT, which has been banned in North America, Europe, and the former Soviet Union but continues to be used in Asia, Africa, and Central and South America where malaria remains endemic, as recommended by the World Health Organisation as a vital contribution to public health protection against malaria.

2.1 Intentionally Produced POPs - on Annex A

The Stockholm Convention's goal for the intentionally produced POPs on Annex A is their elimination from production and use. Imports and exports of these substances have to follow strict provisions and restrictions for exempted uses. Among the intentionally produced POPs, there are eight pesticides plus hexachlorobenzene (HCB) and PCBs. All of the intentionally produced POPs on Annex A have been identified as endocrine disruptors and, with the exception of endrin, as known, probable or possible carcinogens.

2.1.1 Aldrin

Aldrin, an insecticide, is known by a number of trade names including "Aldrec", "Aldrex", "Aldrex 30", "Drinox", "Seedrin", among others. Aldrin is readily metabolised to dieldrin by both plants and animals and therefore, these two compounds are generally treated the same for regulatory purposes [1,2,3]. It is used to control insects such as termites, corn rootworm, wireworms, rice water weevils and, other beetles, and grasshoppers and was especially widely used from the 1950's to the early 1970's on crops such as corn, bananas, pineapples, cotton and potatoes [1,3].

Aldrin is toxic to humans; the lethal dose of Aldrin for an adult man has been estimated to be about 5g, equivalent to 83 mg/kg body weight. Aldrin has low phytotoxicity, with plants affected only by extremely high application rates. The toxicity of aldrin to aquatic organisms is quite variable, with aquatic insects being the most sensitive group of invertebrates, caused by aldrin treated rice and indirectly by consuming organisms contaminated with aldrin. Residues of aldrin were detected in all samples of bird casualties, eggs, scavengers, predators, fish, frogs, invertebrates and soil [1].

As aldrin is readily and rapidly converted to dieldrin in the environment its fate is closely linked to that of dieldrin. Aldrin is readily metabolized to dieldrin in both animals and plants, and therefore aldrin residues are rarely present in animals and then only in very small amounts. Residues of aldrin have been detected in fish in Egypt, the average concentration was 8.8 µg/kg, and a maximum concentration of 54.27 µg/kg [1].

Human exposure results primarily from eating contaminated foods, such as root crops, fish, dairy products and meats [3].

Human health and environmental concerns pertaining to the toxicity and persistence of these compounds, resulted in restrictions on their use, sale, import and outright ban in many developed countries, beginning in

the mid-1970's [4,5]. To date aldrin is banned in Bulgaria, Ecuador, Finland, Hungary, Israel, Singapore, Switzerland and Turkey. Its use is severely restricted in many countries, including Argentina, Austria, Canada, Chile, the EU, Japan, New Zealand, the Philippines, USA, and Venezuela [1]. The last known manufacturer of aldrin and dieldrin, Shell International Chemical Co. (UK), discontinued production of these pesticides in 1989[5]. However, the use of stockpiles has been known to recently occur in some developing countries for application on crops such as bananas.

2.1.2 Chlordane

Chlordane is known by several trade names including "Aspon", "Belt", "Dowchlor", "Niran", "Octachlor", "Tat chlor", and "Velsicol 1068" [1,5]. The types of formulations include emulsifiable concentrates, granular, and soluble concentrates. Chlordane is not used as a single chemical, but is mixed with many related chemicals [6,7]. It has been used as a broad-spectrum insecticide, mainly for non-agricultural purposes in the control of termites. Chlordane has been applied as a subsurface soil treatment for termite control; in underground cables; and above-ground structural application for control of termites and other wood-destroying insects. To a lesser degree chlordane has been applied on crop and livestock. Its agricultural use involve insect control for a number of crops including vegetables, small grains, maize, other oilseeds, potatoes, sugarcane, sugar beets, fruits, nuts, cotton and jute [1,7,8].

Early studies on occupational exposure found no toxic effects in workers involved in the production of chlordane with up to 15 years of exposure. In a survey of 1105 workers associated with pest control, most of whom used chlordane, however, only three attributed illness to it (mild dizziness, headache, weakness). Chlordane exposure has not been associated with increased risk of mortality from cancer. Significant changes in the immune system were reported in individuals who complained of health effects, which they associated with chlordane exposure [1].

Exposure to chlordane occurs primarily from eating crops grown on contaminated soils, such as root crops, corn and citrus foods, from eating contaminated meats, fish and shellfish, or from handling contaminated soil [6,9].

Because of concern about damage to the environment and harm to humans, action to ban the use of chlordane has been taken in Bolivia, Brazil, Chile, Columbia, Costa, Rica, Dominican Republic, the EU, Kenya, Korea, Lebanon, Liechtenstein, Mozambique, Norway, Panama, Paraguay, Philippines, Poland, Saint Lucia, Singapore, Switzerland, Tonga, Turkey, Yemen and Yugoslavia. Its use is severely restricted or limited to non-agricultural uses in Argentina, Belize, Bulgaria, Canada, China, Cyprus, Dominica, Egypt, Honduras, Indonesia, Israel, Mexico, New Zealand, South Africa, Sri Lanka, the USA and Venezuela [1].

2.1.3 Dieldrin

Dieldrin is known by many trade names including "Alvit", "Dieldrite", "Dieldrix", "Illoxol", "Quintox", etc. [1]. Dieldrin has been used in agriculture for soil and seed treatment and in public health for disease vector control for mosquitoes and tsetse flies. It has also been used for veterinary purposes as a sheep dip, and for treating wood and mothproofing of woollen products [1,2].

Dieldrin residues have been detected in air, water, soil, fish, birds and mammals, including humans and human breast milk. As aldrin is readily and rapidly converted to dieldrin in the environment and in organisms, the levels of dieldrin detected likely reflect the total concentrations of both compounds. Diet is the main source of exposure to the general public. Dairy products, such as milk and butter, and animal meats are the primary sources of exposure [1,4]

Dieldrin has been banned in a number of countries due to environmental and human health concerns. Action to ban Dieldrin has been taken in many countries, including Bulgaria, Ecuador, the EU, Hungary, Israel, Singapore and Turkey. Its use is severely restricted in numerous countries, including Argentina, Austria, Canada, Colombia, Cyprus, India, Japan, New Zealand, Pakistan, the USA and Venezuela [1]

2.1.4 Endrin

Endrin, also known as “Compound 269”, “Endrex”, “Epoxide”, “Hexadrin”, “Isodrin”, “Mendrin”, “Nendrin”, etc., was introduced in the early 1950’s [1,10,11,12]. Endrin is a foliar insecticide that has been used primarily on field crops such as cotton, maize, sugarcane, rice, cereals, apples, and ornamental plants. It has also been used as a rodenticide to control mice, voles, etc., in fields and orchards [1,11,13].

The chemical properties of endrin (low water solubility, high stability in the environment, and semi-volatility) favour its long-range transport, and it has been detected in arctic freshwater. The main source of endrin exposure to the general population is residues in food however, contemporary intake is generally below the acceptable daily intake of 0.0002 mg/kg body weight recommended by the United Nations Food and Agriculture Organisation (FAO) / World Health Organization (WHO) Joint Meeting on Pesticide Residues (JMPR) [1,14].

Concerns over the toxicity and persistence of endrin have resulted in the product being banned in several countries including Belgium, Cyprus, Ecuador, Finland, Israel, Philippines, Singapore, Thailand and Togo. Several other countries, such as Argentina, Canada, Chile, Colombia, the EU, India, Japan, New Zealand, Pakistan, USA, and Venezuela have placed severe restrictions on its use [1,10].

2.1.5 Heptachlor

Heptachlor has been used primarily as an insecticide to control crop pests, cotton insects, grasshoppers, and termites. Heptachlor is known by many synonyms and trade names including “Aahepta”, “Agroceres”, “Baskalor”, “Drinox”, “Heptachlorane”, “Heptagran”, “Solepax”, and “Veliscol 104” [1,15].

WHO suggests that food is the major source of exposure of heptachlor to the general population. Exposure to heptachlor occurs primarily through ingestion of residues in crops grown on heptachlor-contaminated soil; fish, dairy products and fatty animals exposed to heptachlor in their food; inhalation in homes treated for termite control; drinking of contaminated water; dermal contact; and through consumption of breast milk from mothers with high exposure [1, 15].

Due to concerns pertaining to the high toxicity of heptachlor, its ability to alter the body’s hormone systems, its potential to damage the nervous systems of both humans and animals, and its implication in the decline of several wild bird populations, the use of heptachlor has been banned in several countries and severely restricted in other. . The use of heptachlor has been banned in Cyprus, Ecuador, the EU, Singapore, Switzerland and Turkey. Its use is severely restricted in Argentina, Israel, Canada, Czechoslovakia, Japan, New Zealand, Philippines, USA and USSR [1,15]. However, heptachlor is still in limited use in several countries including Algeria, Brazil, Eritrea, Japan, Republic of Korea, New Guinea and Togo [16].

2.1.6 Mirex

Mirex is a white crystalline, odourless solid [17]. Synonyms and trade names for mirex include “Dechlorane”, “Ferriamicide” and “GC 1283” [1, 18]. Its main use was against fire ants in the southern United States, but it has also been used to combat leaf cutters in South America, harvester termites in South Africa, Western harvester ants in the US, giant termites in Australia, mealy bug of pineapple in Hawaii and has been investigated for possible use against yellow jacket wasps in the US. Mirex has also been used as a flame retardant in plastics, rubbers, paints, paper, electrical goods, etc. [1, 16, 18, 19].

Mirex is considered as one of the most stable and persistent pesticides. It is highly toxic to human and is considered a potential human carcinogen. Studies on organisms, as well as its persistence, suggest that mirex presents a long-term hazard to the environment. For this reason, the use of mirex has become increasingly restricted in several countries such as Germany and the United States, or banned in others such as Ecuador and Thailand [17]. Mirex is still used in the Northern Territory and northern Western Australia for the control of giant termites (*Mastotermes darwiniensis*) and in China [16].

Humans may be exposed by breathing, touching, or ingesting dust or soil that contain mirex. Exposure may also occur by ingesting contaminated fish or other animals living near hazardous wastes sites [18, 19]

2.1.7 Toxaphene

Toxaphene is a mixture of chlorinated comphenes[1, 20]. It is known by many synonyms and trade names including “Alletex”, “Attac 6”, “Camphechlor”, “Chloro-camphene”, “Kamfochlor”, “Melipax”, “Penphene”, “Toxakil” and “Vertac 90%” [20]. It has been used primarily as an insecticide for the control of cotton insect pests, insect pests on livestock, poultry and a few field crops such as soybeans, peanuts, sorghum, etc. The insecticide was first produced in the U.S. in 1947 and its use was encouraged as a replacement for DDT during the 1960’s and 1970’s [20, 21].

The primary routes of potential human exposure to toxaphene are ingestion of contaminated food and water, dermal contact and inhalation. Manufacturers, farmers and pesticide applicators have the greatest potential risk of exposure. Due to its being banned in many countries, recent food surveys have generally not included toxaphene and hence recent monitoring data are not available [1].

In 1982, the U.S. EPA cancelled the registration of all POPs pesticides, including toxaphene, for most uses as a pesticide or pesticide ingredient, except on specific restricted terms. All registered uses were banned and existing stocks were not allowed to be sold or used in the U.S. after March 1, 1990. Similar bans and restrictions have been imposed on toxaphene usage in other developed countries, however, toxaphene-like pesticide agents are still produced and widely used in India, and many countries in Latin America, Eastern Europe, the former Soviet Union, and Africa [21].

Beginning in the early 1980’s, the use of toxaphene was severely restricted in some jurisdictions due to concerns relating to its toxicity and its environmental persistence. Toxaphene has been banned in 37 countries, including Austria, Belize, Brazil, Costa Rica, Dominican Republic, Egypt, the EU, India, Ireland, Kenya, Korea, Mexico, Panama, Singapore, Thailand and Tonga. Its use has been severely restricted in 12 other countries, including Argentina, Canada, Columbia, Dominica, Honduras, Nicaragua, Pakistan, South Africa, Turkey and Venezuela. [1].

2.1.8 HCB – An Industrial Chemical and a Pesticide

The Stockholm Convention has listed hexachlorobenzene (HCB) and polychlorinated biphenyls (PCB) as the industrial chemicals targeted for elimination and ban. PCB has been on the list of banned substances for many years in several jurisdictions. HCB on the other hand has been added to the list of banned substances more recently. In addition, HCB is produced as a by-product of thermal processes like incineration.

HCB is a white crystalline solid or crystal and is used as a fungicide. It was originally introduced in 1940’s as a seed-dressing for cereal crops to prevent fungal disease. HCB has also been used in various industrial processes, for example, as a fluxing agent in the manufacture of aluminium and as a peptising agent in the production of rubber for tires. It is also produced as an unintentional by-product of combustion processes involving chlorinated compounds and as a by-product in the manufacture of certain chlorinated pesticides and industrial chemicals. In this latter group are chlorinated solvents, such as carbon tetrachloride, perchloroethylene, trichloroethylene and chlorinated benzenes [22].

Human exposure to HCB may occur through several pathways including consumption of dairy products or meat from cattle grazing on contaminated pastures; consuming low levels in food, eating or touching contaminated soil; drinking small amounts in contaminated water; inhaling low levels in contaminated air; drinking contaminated breast milk from exposed mothers; occupational exposure from the use or production of HCB; and exposure to HCB as a by-product from other industrial processes, such as waste incineration [22].

HCB is toxic to both humans and animals when long-term exposure occurs. Its main health effect is liver disease. HCB is also known as an endocrine disruptor and probable human carcinogen [22, 23]. HCB was

voluntarily cancelled for use as a pesticide in 1984 in the U.S. and is no longer commercially manufactured as an end product in that country. It is also banned in India and Japan and its use is restricted in several other countries. However, it may still be in use in several countries including Bolivia, Brazil, Bulgaria, Cameroon, China, Ecuador, Eritrea, Madagascar, Nigeria, Poland and the Russian Federation [16].

2.1.9 PCBs

PCBs are a group of industrial chemicals that were commercially produced worldwide on a large scale between the 1930s and 1970s. PCBs have been sold under numerous trade names including “Asbestol”, “Askarel”, “Bakola”, “Chlorinol”, “Chlorphen”, “Dykanol”, “Pyranol”, “Saft-T-Kuhl” and “Sovol” [24]. Their usefulness stems from their chemical stability and heat resistance, and they have been extensively employed as components in two types of applications: 1) closed uses – dielectric fluids in electrical equipment equipment such as transformers, capacitors, heat transfer and hydraulic systems; and 2) open uses – as pesticide extenders, sealants, in carbonless copy paper, industrial oils, paints, adhesives, plastics, flame retardants and to control dust on roads. PCBs are also created as unintentional by-products during the combustion of materials containing chlorine in any form as well as during the manufacture of various chlorine-containing chemicals, such as ethylene dichloride.

In the 1970s, owing to concerns pertaining to their human toxicity, suspected carcinogenicity, and environmental persistence, countries of the Organization for Economic Co-operation and Development (OECD) restricted the use of PCBs to closed systems [24]. Manufacture for export to non-OECD countries continued in Europe until 1983. Most countries of the world now restrict the use of PCBs. To date, 16 countries prohibit the import of PCBs, whereas six others allow the import of PCBs only under special circumstances. However, PCBs are in use in numerous countries worldwide including Algeria, Angola, Antigua and Barbuda, Argentina, Benin, Bulgaria, Burkina Faso, China, Cote d’Ivoire, Croatia, Eritrea, India, Iran, Jamaica, Lesotho, St. Lucia, Macedonia, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Nigeria, Poland, Korea, South Africa, Sudan, Togo, Uganda, Uruguay and Zimbabwe [16].

Ongoing releases of PCBs to the environment occur from fires, spills, and leakages from closed systems; evaporation or leakage from landfills or PCB storage sites; incineration of waste containing PCBs (which were once used in a wide array of consumer products); and incomplete incineration of waste PCBs. PCBs are classified as probable human carcinogens and produce a wide spectrum of adverse effects in animals, including reproductive toxicity and immunotoxicity [25].

The most common route of PCB entry into humans is ingestion of contaminated food, including fish; however, PCBs may also be inhaled and absorbed through the skin.

2.2 Intentionally Produced POPs on Annex B

2.2.1 DDT

DDT, the first of the chlorinated organic insecticides, came into wide commercial usage during World War II [26]. It does not occur naturally in the environment [27]. It was initially used with great effect to combat insect-borne human diseases such as malaria and typhus. DDT was also used as a broad-spectrum pesticide to control insect pests on crop and forest lands, around homes and gardens, and for industrial and commercial purposes [28].

DDT was banned by most developed countries during the 1970’s due to its damaging effects on the environment. However, DDT is still used today for vector control to prevent malaria transmission and for controlling epidemics in some countries, such as Algeria, Bangladesh, Brazil, China, Comoros, Costa Rica, Ecuador, Eritrea, Ethiopia, India, Iran, Kenya, Madagascar, Malawi, Mauritius, Morocco, Mozambique, New Guinea, Korea, Russian Federation, Saudi Arabia, South Africa, Sudan, Swaziland, Togo, Uganda, Tanzania, Venezuela, Yemen, Zambia and Zimbabwe [16]

The WHO supports the use of DDT to control malaria so long as it is only used for indoor residual spraying in accordance with WHO guidelines [29].

DDT is introduced to the body through the lungs, gastro-intestinal tract and skin. The primary means of human exposure include, exposure to DDT dust and vapour from fumigated fields and forests; contact with mothproofing products; and ingestion of fruits and vegetables treated with DDT-containing pesticide [27, 30].

The Stockholm Convention has categorized DDT under its restricted category for production and use. DDT is slated to be eliminated from production and use, except for countries that indicated a need for its continued production and use for disease vector control use and for use as an intermediate in the production of dicofol.

2.3 Unintentionally Produced POPs - Industrial Waste By-Products on Annex C

The Stockholm Convention's goal for the unintentionally produced POPs on Annex C is the continuing minimization and, where feasible, ultimate elimination. The unintentionally produced POPs on Annex C are dioxins, furans, hexachlorobenzene, and polychlorinated biphenyls.

2.3.1 Dioxins and Furans

Dioxins (polychlorinated dibenzo-p-dioxins, or PCDDs) and furans (polychlorinated dibenzofurans, or PCDFs) are two groups of chemicals with similar chemical structures, each varying according to the number and position of chlorine atoms attached to the dioxin or furan moiety. There are 75 different dioxins and 135 different furans [31]. The number and placement of their chlorine atoms also determine their physical, chemical, and toxicological properties.

The most significant dioxin sources in the past have been waste incinerators (including municipal waste incinerators), iron ore sintering plants, production and use of the wood preservative pentachlorophenol, and pulp and paper mills using chlorine for the bleaching process. PCBs are the most significant potential source of furans, a fact that underlies the concern about accidental burning of PCBs.

A number of types of cancer, as well as total cancer incidence, have been related to accidental and occupational exposure to one particular dioxin (TCDD). The most toxic dioxin is TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin), which appears to account for most of the observed toxicologicaleffects. In addition, an increased prevalence of diabetes and increased mortality due to diabetes and cardiovascular diseases has been reported. In children exposed to dioxins effects on neurodevelopment, neurobehaviour and effects on thyroid hormone status have been reported at exposures at or near background levels. At higher exposures, due to accidental exposure (Yusho and Yu Cheng populations), children exposed transplacentally to dioxins show skin defects (such as chloracne), tooth mineralisation defects, developmental delays, behaviour disorders, decrease in penile length at puberty, reduced height among girls at puberty and hearing loss. Humans, sea birds and aquatic mammals are in principle the most affected, as they are at the end of the aquatic trophic chain of these products which bioaccumulate in animal fat. The critical effects can include neurobehavioural changes and immunosuppression.

Dioxins and furans enter the human body by ingestion, inhalation, and skin penetration. The most important route for human exposure to dioxins is food consumption, contributing for more than 90 % of total exposure, of which products of fish and other animal origin account for approximately 80 % of the overall.

2.3.2 PCBs and HCB

Hexachlorobenzene (HCB) and polychlorinated biphenyls (PCBs) are aromatic organochlorines that are unintentional by-products of many of the processes in which dioxins and furans are formed, such as combustion of chlorinated halogens and various industrial production processes. Exposures to these compounds through the food chains are the predominant exposure pathways.

2.4 POPS WASTES GENERATORS

The Basel Convention defines “wastes” as *substances or objects, which are disposed of or are intended to be disposed of or required to be disposed of by provisions of national law. A stockpile of a material could be considered a waste if it is intended for disposal or is required to be disposed of.* As was noted earlier, Article 6 of the Stockholm Convention specifies measures to reduce and eliminate releases from POPs stockpiles and wastes.

POPs wastes may be generated in various ways including:

- during their intentional manufacture;
- during industrial and other processes as unintended wastes or by-products
- during their sales/ marketing/ utilisation by sellers/ wholesalers/ retailers/ end-users;
- during the decommissioning/ removal/ transfer etc. of materials containing POPs; and
- during their disposal.

For pesticides, consisting of or containing POPs, these can become wastes when:

- a surplus stock is purchased or donated, and stock is in excess of need;
- the product has been prohibited or severely restricted for health or environmental reasons (e.g. through banning, registration withdrawal, or change in government policy), while stocks are still being held;
- the product has deteriorated as a result of improper or prolonged storage and can no longer be used according to its label specifications and instructions for use, nor can it be easily be reformulated to become usable again; and
- the product is not suitable for its intended use and cannot be used for other allowed purposes, nor can it be easily modified to make it usable again [32].

Other POP-containing products can become waste when:

- solutions generated during rinsing and cleaning of equipment/ product containers are released;
- residues exist in partially cleaned or un-cleaned containers; and
- soil or other material is contaminated with POPS pesticides either from spills or excessive application to such an extent that prompts a decision to remediate in an environmentally sound manner.

PCB containing waste can be found in numerous locations and as a result of many different activities. Following are some of the key causes for the generation of PCB-containing wastes:

- repairs and decommissioning of PCB equipment;
- reuse and recycling of used equipment contaminated with PCBs;
- cross-contamination, such as the contamination on non-PCB transformers with PCB oil due to improper refilling practices;
- liquid content contained in discarded or disused equipment, such as PCB transformers and capacitors;
- contaminated soil and solid waste arising from clean-up operations.
- waste (upholstery, padding and insulation material) derived from the shredding of contaminated cars and appliances; and
- leakage during the transfer of PCB-containing waste from one location to another or from one piece of equipment to another.

Releases of PCBs into the environment can come from:

- inadvertent emissions by chemical plants (e.g. organochlorines) to air or waste water;
- releases of PCBs to air and in ashes and other residues as a result of their formation during combustion of chlorine-containing materials;
- leakage during the transfer of PCB-containing waste from one location to another or from one piece of equipment to another; and
- accidental releases of material containing PCBs during fires and other emergencies, especially in power distribution networks, etc.

By deposition of dioxins and furans emitted, many materials are contaminated to a greater or lesser degree by these substances. These materials upon becoming waste, will be dioxin and furan-containing waste.

Emissions of HCB result from the same type of thermal and chemical processes as those emitting dioxins and furans, and HCB is formed by a similar mechanism. Releases of HCB in the environment may come from:

- incineration of waste
- cement and aggregate kilns;
- fugitive emissions from the point of application of chlorinated pesticides;
- emissions from open trash burning;
- leachate from municipal or industrial landfills;
- residues in wood treated with wood preservative pentachlorophenol (PCP); and
- discharges from sewage treatment plants arising from domestic, industrial and commercial discharges and/or storm runoff.

HCB-containing waste may include:

- wastes generated during the production of chlorinated solvents;
- waste associated with manufacture of chlorinated pesticides;
- the manufacture of waste from chemical industries, in particular alkalis and chlorine;
- waste from secondary aluminium processing;
- waste containing HCB;
- emissions, ashes and runoff from open trash burning;
- leachate from municipal or industrial landfills;
- residues in wood treated with wood preservative pentachlorophenol; and
- discharges and sludges from sewage treatment plants arising from domestic, industrial and commercial discharges and/or storm runoff.

Dioxins and furans, and to a lesser extent HCB and PCBs may be emitted from stationary and mobile sources as a result of thermal and other industrial processes involving organic matter and chlorine, e.g. through incomplete combustion or through other chemical reactions.

The Stockholm Convention identifies the unintentional sources of dioxins and furans, PCBs and HCB as follows:

Part II: Source categories

Polychlorinated dibenzo-p-dioxins and dibenzofurans, hexachlorobenzene and polychlorinated biphenyls are unintentionally formed and released from thermal processes involving organic matter and chlorine as a result of incomplete combustion or chemical reactions. The following industrial source categories have the potential for comparatively high formation and release of these chemicals to the environment:

- (a) Waste incinerators, including co-incinerators of municipal, hazardous or medical waste or of sewage sludge;

- (b) Cement kilns firing hazardous waste;
- (c) Production of pulp using elemental chlorine or chemicals generating elemental chlorine for bleaching;
- (d) The following thermal processes in the metallurgical industry:
 - (i) Secondary copper production;
 - (ii) Sinter plants in the iron and steel industry;
 - (iii) Secondary aluminium production;
 - (iv) Secondary zinc production.

Part III: Source categories

Polychlorinated dibenzo-p-dioxins and dibenzofurans, hexachlorobenzene and polychlorinated biphenyls may also be unintentionally formed and released from the following source categories, including:

- (a) Open burning of waste, including burning of landfill sites;
- (b) Thermal processes in the metallurgical industry not mentioned in Part II;
- (c) Residential combustion sources;
- (d) Fossil fuel-fired utility and industrial boilers;
- (e) Firing installations for wood and other biomass fuels;
- (f) Specific chemical production processes releasing unintentionally formed persistent organic pollutants, especially production of chlorophenols and chloranil;
- (g) Crematoria;
- (h) Motor vehicles, particularly those burning leaded gasoline;
- (i) Destruction of animal carcasses;
- (j) Textile and leather dyeing (with chloranil) and finishing (with alkaline extraction);
- (k) Shredder plants for the treatment of end of life vehicles;
- (l) Smoldering of copper cables;
- (m) Waste oil refineries.

While many countries have already taken steps to ban or severely restrict some intentionally produced POPs, many others continue to produce and use or otherwise create these chemicals or build facilities that are known to generate by-products of POPs. For this reason, it is expected that POPs will continue to accumulate for some time to come. Enormous stockpiles of POPs wastes continue to exist throughout the world [33].

UNEP reports that tens of thousands of tonnes of old pesticides are stored throughout the developing world, usually in inadequate or even dangerous conditions. UNEP preliminary estimates indicate that POPs comprise about 30% of these stocks [34]. The FAO has been foremost in compiling inventories of obsolete pesticide stocks in Africa and the Near East. Inventories have now been completed for 53 countries in these regions and a total of about 47,000 tonnes of obsolete pesticides have been identified. The FAO programme was expanded to Latin America in 1998 where 33 countries were invited to carry out inventories; five had responded by 2001 identifying 1,895 tonnes of obsolete pesticide. In early 2001, FAO expanded its programme to Asia where 21 countries were invited to participate [35, 36].

In Asia and Latin America, where there is less available data, it is believed that as much as 88,000 tonnes of obsolete pesticides are held, and in the Former Soviet Union, early estimates indicate stockpiles of at least 165,000 tonnes. These numbers are conservative as they pertain solely to obsolete stockpiles and do not include the broader spectrum of waste pesticides. Also, these estimates do not always include the large quantities of contaminated soil and thousands of contaminated empty containers [37].

In the case of PCBs, it is very difficult to assess waste volumes, as the definition of PCB waste is determined by its content. In general, all wastes containing at least 50 mg/kg (50 ppm) of PCBs are considered as PCB waste. However, the PCB content of large quantities of PCB-contaminated liquid and solids is unknown. In 1987, the OECD estimated a total volume of over 650,000 tonnes of PCB-

contaminated waste in member states. Adding the volumes from non-OECD member states will significantly increase the total global volume.

The total amount of HCB waste stockpiled worldwide is unknown, however, inventories in four countries total in excess of 53,000 tonnes of drummed HCB wastes and 550,000 tonnes of HCB-contaminated soils. In addition to the “legacy” problem of HCB stockpiles, these chemicals are still being created during various chemical and industrial processes.

2.5 SCOPE AND METHODOLOGY

Environmentally sound management is defined in the Basel Convention as taking all practicable steps to ensure that hazardous wastes or other wastes are managed in a manner, which will protect human health and the environment against adverse effects, which may result from such wastes.

(NOTE: Greenpeace’s comments as appeared on pg. 9 of their detailed comments regarding the October 2002 draft (To include or not??))

In this context, the criteria to assess environmentally sound management include the following:

- a) There exists a regulatory infrastructure and enforcement structure that ensures compliance with applicable regulations;
- b) Sites or facilities are authorized and of an adequate standard of technology and pollution control to deal with the hazardous wastes in the way proposed, in particular taking into account the level of technology and pollution control in the exporting country;
- c) Operators of sites or facilities at which hazardous wastes are managed are required, as appropriate, to monitor the effects of those activities;
- d) Appropriate action is taken in cases where monitoring give indications that the management of hazardous wastes have resulted in unacceptable emissions; and
- e) Persons involved in the management of hazardous wastes are capable and adequately trained in their capacity [38].

Countries also have obligations to avoid or minimise waste generation and to ensure the availability of adequate facilities for their waste, so as to protect human health and the environment.

In this context, countries should, inter alia:

- a) Take steps to identify and quantify the types of waste being produced nationally;
- b) Use best practice to avoid or minimise the generation of hazardous waste, such as the use of cleaner production methods or approaches;
- c) Provide sites or facilities authorized as environmentally sound to manage their wastes, in particular hazardous wastes [38].

In addition, enforcement and monitoring could be enhanced through international cooperation.

These Guidelines are structured as follows:

Chapter 3 discusses the international regulatory regime, in particular the Stockholm and Basel conventions. It summaries key convention articles as they relate to the current project, such as Articles 5 and 6 of the Stockholm Convention. This section also discusses POPs wastes generators (production and use).

Chapter 4 presents steps of Environmentally Sound Management (ESM) guidelines for POPs wastes. In particular, it defines ESM as well as steps for identification and characterisation, handling, storage, transportation and interim storage/treatment before final disposal and typical sampling requirements.

Chapter 5 describes technologies currently available for destruction/irreversible transformation of various POPs. A decision making table for POPs wastes is also provided.

Chapter 6 discusses the issues concerning criteria for low level of POPs.

3.0 BASEL AND STOCKHOLM CONVENTIONS

3.1 BASEL CONVENTION

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted in 1989 in response to widespread concern about the dumping of hazardous wastes in developing countries by companies from developed countries. It entered into force in 1992 and by December 2002 there were 153 Parties to the Basel Convention.

The December 1999 Basel Declaration adopted by the fifth meeting of the Conference of the Parties (COP5) states that:

The fundamental aims of the Basel Convention [are] the reduction of transboundary movements of hazardous wastes and other wastes subject to the Basel Convention, the prevention and minimisation of their generation, the environmentally sound management of such wastes and the active promotion of the transfer and use of cleaner technologies.

As wastes, all of the POPs currently listed in the Stockholm Convention are classified as hazardous wastes in Annex VIII of the Basel Convention (under A1180, A3180, A4030, A4110 and A4140). Article 2, paragraph 8 of the Convention defines 'Environmentally Sound Management (ESM)' as taking all practicable steps to ensure that hazardous wastes or other wastes are managed in a manner which will protect human health and the environment against the adverse effects which may result from such wastes. The notification and consent procedures of the Convention require that any transboundary movement (export/import/transit) is only permitted when the movement itself and the ultimate disposal of the concerned hazardous wastes are environmentally sound. The Importing Party must consent to the import in writing. In addition, Articles 4.2(c), 4.2(g), and 4.8, in particular, provide obligations regarding the ESM of wastes subject to the Basel Convention [39].

Annex IV to the Convention contains the list of disposal operations. It identifies a list of operations that occur in practice that trigger the prior written informed consent procedure. Once a notification is received by the competent authority, the obligations in Article 4 (2)(e) which require that the transboundary movement of hazardous wastes be 'managed' in an environmentally sound manner are triggered. 'Management' is defined in the Convention as "the collection, transport and disposal of hazardous wastes or other wastes, including after-care of disposal sites" (Art.2.2) [39].

The Conference of the Parties to the Basel Convention has adopted several sets of technical guidelines prepared by its Technical Working Group that concern or are related to POPs as wastes. These are:

(a) Technical guidelines on Annex IV Disposal Operations:

- Specially engineered landfill (D5)
- Biological treatment (D8)
- Physico-chemical treatment (D9)
- Incineration on land (D10)
- Used oil re-refining or other reuses of previously used oil (R9)

(b) Technical guidelines on Annex I Waste Streams:

- Waste mineral oils unfit for their originally intended use (Y8)
- Waste substances and articles containing or contaminated with PCBs and/or

polychlorinated terphenyls (PCTs) and/or polybrominated biphenyls (PBBs) (Y10)

- Biomedical and healthcare wastes (Y1; Y3)
- Plastics wastes (B3010)
- Waste lead-acid batteries (A1160)
- Full and partial dismantling of ships

In this regard, it should be emphasized that, for instance, the technical guidelines on Specially Engineered Landfill states that there are a number of hazardous wastes for which landfill disposal is not appropriate and cannot be recommended; these are:

- Hazardous liquid wastes and hazardous materials containing free liquids
- Highly volatile and flammable liquid wastes
- Wastes containing appreciable quantities of mineral oils
- Spontaneously flammable or pyrophoric solids
- Clinical wastes (such as infectious wastes; sharps; etc.)
- Strongly oxidizing/reducing wastes
- Shock sensitive explosives
- Compressed gases
- Highly reactive wastes
- Water soluble non-convertible materials
- Persistent organo-halogen compounds, and
- Volatile materials of significant toxicity

The obligations in the Basel Convention as well as the supportive technical guidelines adopted by the COP pursuant to Article 4(8) provide a set of internationally accepted guidance for the environmentally sound management of POPs as wastes.

While preparing technical guidelines, the Parties have given due consideration to the specific situation of developing countries, in particular to those countries that do not have the technical capacity, the necessary facilities or suitable disposal sites to dispose of these wastes in an environmentally sound manner or for which locally affordable and sound solutions do not exist for certain waste streams (e.g. used oils, contaminated soil). In addition, because new technologies are being developed to dispose of POPs as wastes, the Parties retain the possibility to adjust to technology changes through the preparation of new or expanded technical guidelines for the ESM of these wastes as required under the Basel Convention [39].

The Technical Working Group has the view that operations D9 (physico-chemical treatment) and D10 (incineration on land) as specified under Annex IVA of the Basel Convention, are the preferred options for the disposal of hazardous wastes which consists of, contain, or are contaminated with POPs. (In the case of PCBs, this means that wastes with a concentration level of PCBs lower than 50 mg/kg are not hazardous wastes). The Technical Working Group notes, however, that annual reports submitted by Parties for the year 1997 on import/export contain information in regard to other disposal options for the Basel Convention Annex I waste streams, in particular for Y10 (PCBs, PCTs, PBBs) [39].

The sixth meeting of the Conference of the Parties (COP6) of the Basel Convention in December 2002 adopted decisions encouraging the Open-ended Working Group (OEWG) to complete the preparation of the technical guidelines on the environmentally sound management of POPs as wastes in 2003 for eventual adoption by the seventh meeting of the Conference of the Parties (COP7). It also requested the OEWG to continue to reinforce its cooperation with the appropriate subsidiary body(ies) of the Stockholm Convention on POPs to ensure consistency in implementation and mutual support between the Basel and the Stockholm Conventions.

3.2 STOCKHOLM CONVENTION

The Stockholm Convention on POPs was adopted on 22 May 2001 and has been signed by 150

Governments and the EU. The Convention will enter into force on the ninetieth day after the date of deposit of the fiftieth instrument of ratification, acceptance, approval or accession.

The objective of the Convention, as stated in Article 1, is “to protect human health and the environment from persistent organic pollutants (POPs)”. The Convention obliges Parties to:

- take measures to eliminate releases from intentional production and use, unintentional production, and stockpiles and wastes of 12 POPs (Articles 3, 5 and 6);
- eliminate production and use of nine intentionally produced POPs, subject to certain time-limited and general exemptions (Annex A: aldrin, chlordane, dieldrin, endrin, heptachlor, HCB, mirex, toxaphene, and PCBs)
- take measures to restrict the production and use of one intentionally produced POP (Annex B: DDT);
- reduce the total releases of unintentionally produced POPs with the goal of their continuing minimisation and where feasible, ultimate elimination (Annex C: polychlorinated dibenzo-p-dioxins, dibenzofurans, HCB, PCBs);
- take appropriate measures so that waste POPs, including products and articles upon becoming wastes, are handled, collected, transported and stored in an environmentally sound manner, and are disposed of in such a way that the POPs content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of POPs (or are otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the POPs content is low) (Article 6);
- not to permit POPs waste to be subject to disposal operations that may lead to recovery, recycling, reclamation, direct reuse or alternative uses of POPs (Article 6.1 (d)(iii))
- encourage the implementation of national regulations to prevent development of new chemicals with POPs characteristics by promoting changes in industrial materials, processes, and products that can create POPs; and
- Article 6 of the Stockholm Convention concerning measures to reduce or eliminate releases from stockpiles and wastes left open a number of definitional issues. It required the COP to cooperate closely with the appropriate bodies of the Basel Convention in addressing these, in particular to establish appropriate levels of destruction and irreversible transformation for POPs wastes; to determine what methods would constitute environmentally sound disposal; and to establish the concentration levels that would define low POPs content. The Conference of Plenipotentiaries that adopted the Stockholm Convention in May 2001 also invited Basel Convention bodies to cooperate closely on these matters and to prepare technical guidelines on the environmentally sound management of POPs.

3.3 BASEL AND STOCKHOLM CONVENTIONS INTERRELATIONSHIPS

Some of the key interrelationships between the Basel and the Stockholm convention are:

- all of the POPs currently listed in the Stockholm Convention are also classified as hazardous wastes under the Basel Convention;
- both conventions require POPs wastes to be managed in accordance with ESM practices, but the Stockholm Convention does not allow POPs wastes to be recovered, recycled or reused;
- the COP to the Basel Convention has adopted several sets of technical guidelines prepared by its Technical Working Group that concern, or are related to, POPs as wastes including technical guidelines on certain disposal operations and technical guidelines on PCBs; and
- Article 6.2 of the Stockholm Convention states that the COP shall cooperate closely with the appropriate bodies of the Basel Convention, inter alia, to establish appropriate levels of destruction and irreversible transformation, determine methods that constitute environmentally sound disposal, and establish concentration levels of chemicals to define “low POPs content” for the purposes of Article 6.1 of the Convention.

4.0 ENVIRONMENTALLY SOUND MANAGEMENT

This chapter identifies a proposed approach to be taken to manage POPs in an environmentally sound manner. The management guidelines presented are intended to be generic/global guidelines. It is acknowledged that many developed countries have already implemented management systems/procedures that are specific to their circumstances, and may surpass the requirements specified in this document. The guidelines recommended herein should be considered as the minimum requirements for identification, storage, handling and disposal/destruction of POPs wastes.

4.1 ENVIRONMENTALLY SOUND MANAGEMENT (ESM) PRINCIPLES

Under the Basel Convention, "Environmentally sound management of hazardous wastes or other wastes" means taking all practicable steps to ensure that hazardous wastes or other wastes are managed in a manner, which will protect human health and the environment against the adverse effects, which may result from such wastes [40].

The core performance elements of ESM are those that are applicable to all evaluation, dismantling, refurbishment, pre-treatment, treatment and disposal of wastes. According to the Stockholm Convention, recovery and recycling are, however, not applicable to POPs wastes. This requires that each destruction and/or management facility should:

- have adequate regulatory infrastructure and enforcement to ensure compliance with applicable regulations;
- be appropriately authorized;
- have waste minimisation/ recovery/ recycling procedures (Note: Recovery and recycling procedures are not applicable to POPs wastes);
- be appropriately certified under an applicable Environmental Management System;
- have an appropriate operational monitoring and reporting programme;
- have an operational inspection and recording programme for all input and output materials;
- have appropriate in-house record keeping;
- have an appropriate and verified emergency plan;
- have an appropriate and operative training programme for its personnel; and
- have an adequate financial guarantee for emergency situations and closure.

The above ESM requirements are applicable to countries and facilities involved with POP waste management. Some of the aspects of these ESM requirements are described in detail in the following sections.

4.2 STEPS FOR IDENTIFICATION AND CHARACTERISATION

It is a challenging task to establish norms and criteria for identifying and characterizing POPs wastes. The challenge is further heightened by the complexity of the government management systems in both developed and developing countries, their regulatory regimes, labelling, storage handling and disposal requirements, and reporting and monitoring requirements. These vary from country to country and also within countries and can be very different from one jurisdiction to the next. Therefore the task of developing steps for identifying and characterizing POPs wastes in generic terms is complicated. The following describes some of the key elements for the identification and characterisation of POP wastes.

4.2.1 Identification and Characterisation of Pesticide Wastes

Pesticide wastes can be generated during their manufacture, storage, handling, transportation, application, and non-use and eventual obsolescence. Several types of wastes from pesticide end-users and applicators are common including:

- rinse water - solutions used to rinse application equipment and product containers;
- empty containers – containers that retain pesticide residue (unless triple rinsed);
- unused pesticides – unusable or unidentifiable material; and
- contaminated soil – soil or other material contaminated from spills [41].

Considering that nine of the twelve POPs are pesticides, and that some of them are still actively being manufactured and used, the issue of waste identification and characterisation of POPs pesticides becomes even more important.

In order for identification to be successful, the national government should have cooperation of pesticide waste owners and generators along with a reliable administrative process for collection and storage of this information. The identification of pesticide wastes, especially pesticides identified as POPs, should include:

- The passing of a national regulation clearly and precisely listing the pesticides it wishes to identify and control. The regulation should stipulate a centralized management and registry system and an organisation (competent authority) to effectively deal with pesticide management waste identification.
- The competent authority should provide guidelines for the importer/ manufacturers and exporters and users on aspects relating to:
 - minimising risk from their products becoming waste and causing harm;
 - licensing and ensuring proper feedback;
 - appropriate practices during sale/ storage/ distribution/ use and disposal to minimise generation of waste;
 - product stewardship – return supply chain;
 - product return policy – taking back used containers/ bags/ unused stocks;
 - effective training of pesticide users;
 - public/ community campaigns for awareness building; and
 - management and disposal of all collected waste based on Stockholm/ Basel guidelines.
- The competent authority should regulate the role of suppliers/ distributors and users of POPs pesticides on aspects relating to:
 - storage and stock control of pesticides;
 - construction/ maintenance and operations of pesticide warehouses;
 - management of damaged/ contaminated materials;
 - container handling, storage and disposal including returns to manufacturers;
 - small quantities sales; and
 - proper labelling, placarding and safeguarding.
- The competent authority should assume a leading role in the following areas to assist the end users of POPs pesticides: [With the exception of specific and general exemptions, the use of POPs pesticides other than DDT (see Annex B of the Stockholm Convention) is to be prohibited by Parties to the Stockholm Convention].
 - provide training and information programmes on different types of pesticides and their uses;
 - provide training, literature and other information on avoiding the use of pesticides and the substitution of alternatives;
 - provide training on the purchase of pesticides – to avoid surplus product and ensure the correct pesticide is purchased;
 - product containment and disposal options;
 - labelling, storage, handling and safeguarding;
 - control of empty containers; and
 - management of unwanted pesticides.

All of the above can be achieved if governments in the member countries implement measures to identify and quantify the unwanted stockpiled POPs wastes in their jurisdictions. The following are some key action items:

- the programme should encompass the following waste streams: a) unwanted stocks of pesticides; and b) contaminated environmental media due to unsound management of unwanted stocks of pesticides;
- public/private partnership should be enhanced;
- country alliances should be created for implementation assistance;
- comprehensive public outreach programs should be created to disseminate information about the hazardousness of the materials involved and their potential to cause harm to human health and environment;
- the dissemination of information on proven alternative technologies; and
- strong implementation of the programme action plan.

4.2.2 Identification and Characterisation of PCB Wastes

The PCB, PBB and PCT Technical Guidelines developed under the Basel Convention should facilitate implementation of Stockholm Convention obligations with respect to ESM of PCB wastes. To successfully identify and characterize PCB wastes, the national government should have the cooperation of PCB waste generators along with a reliable administrative process for collection and storage of the information gathered.

A regulatory agency (central authority) should be established or responsibility assigned to an appropriate existing agency. The identification of PCB wastes should include:

- the passing of regulations establishing specialized management of in-use and waste PCBs, stipulating clear definitions for PCB equipment, PCB-contaminated equipment, PCB wastes (indicating concentrations as necessary), PCB storage, PCB disposal, etc. The regulations should also require that PCB waste generators identify their equipment to the appropriate authorities in order to establish a national inventory, comply with specified labelling, reporting and other guidelines and cooperate with government inspectors [43]. These regulations also include a due date for initial reporting and subsequent reporting when any changes are made to the inventory;
- on the basis of the obligatory notifications from holders of PCB-containing equipment and of the results of inspections and additional surveys, the competent authorities can establish an inventory (national, regional, etc.);
- the development of an inventory of potential PCB waste generators including facilities that are likely to have in use or in storage large inventories of PCBs or PCB-containing equipment, such as public utilities, waste disposal sites, large energy dependent facilities including factories, institutions (hospitals, schools, etc.). This may be done by preparing an inventory survey requesting potential facilities to report to a central agency (e.g. Ministry of the Environment) each unit of PCB and/ or PCB-contaminated equipment (e.g. transformers, capacitors, heat transfer equipment, fluorescent lamp ballast, etc.) and the quantities of PCB liquid contained in each unit in use or in storage. Likewise, quantities of contaminated soil, sludge and other material may be required. Quantification of in-use and waste PCBs should be maintained in two separate, but linked, databases;
- the conduct of site visits of a representative sample of facilities, by agents of the competent authority, to verify the inventory information provided in the initial survey. Government agents responsible for dealing with industries and preparing the inventory should be trained in all aspects of PCBs and PCB wastes. They should be knowledgeable of identification techniques, health and safety issues associated with them, methods for the set up and maintenance of the national inventory and how to conduct audits and inspections. The competent authority should undertake several trial PCB waste audits with some of the major industries with PCB wastes. These audits will serve three main purposes:

- allow inspectors to familiarize themselves with the inventory process and actual on-site conditions;
 - provide another form of consultation with industry; and
 - allow for a more accurate update of the national inventory [42].
- update of the national inventory with the information obtained during the data verification audits. This should be a computerized database ready for data input as well as the necessary trained staff. Inventory information should be kept as up to date as possible and assistance should be provided to industries via manuals, help lines and/or website information. Additional profile can be raised through the implementation of an inspection program, which would also act as a quality control measure for reported information;
 - the inventory should include the following information: name and address of equipment holder, location and description of the equipment, the quantity of PCBs contained therein, and dates and types of disposal or decontamination envisaged.
 - enforcement of a labelling system. All equipment inventoried shall be labelled. Proper labelling is important as it provides immediate identification of PCB wastes, informs company officials of any special handling or disposal techniques for the substance, alerts personnel to the presence of PCB wastes in the event of a spill or leakage and provides assistance for all involved in maintaining PCB inventories. The proper labelling of PCB equipment will ensure that it is correctly identified when it enters the waste stream during disposal and decommissioning;
 - a requirement for notification procedures that will ensure the update of the national inventory whenever equipment have been taken out of use and placed into storage as wastes or have been disposed;
 - the development of requirements in regulations and procedures for suspected PCB wastes to be sampled and sent for analysis;
 - on the basis of the inventory, a national plan on the disposal of PCB-containing equipment could be developed in order to ensure that the deadline of 2025 is met and that by that time all PCB-containing equipment will be out of use on the basis of the timetable of disposal; and
 - the plan should assess the national disposal capacity of the country and the eventual necessity to develop such infrastructure or rely on other countries for the disposal of these equipment and PCB waste.

Brief description of potential PCB waste categories that may be included in a national inventory is provided in the Table 3.1. Key action items required by each country should address the following:

- Assessment plan
- Prevention plan
- Treatment and disposal plan

Implementation of these plans would be greatly facilitated if the jurisdictional government has a committed action outreach plan created in public/private partnership to collect the necessary information and to disseminate the knowledge to the stakeholders on storage, handling, transport, handing over of the material to authorised carriers/ transfer stations/ agents.

TABLE 3.1
POTENTIAL PCB WASTE CATEGORIES FOR NATIONAL INVENTORY

Category	Description
Aqueous Waste	Wastes from a variety of sources may be contaminated with PCBs that are associated with suspended matter.
Askarels	A mixture of PCBs and tri-and tetrachlorobenzene. This was the original PCB-containing fluid used. It is a clear liquid with a density of approximately 1.5 kg/L. PCB content ranges from 40-65%.
Concentrated Decontamination Flushings	The first flushings from decontamination of a transformer or solvent washing of solid PCB waste. PCB content is usually within 1-10%.

Category	Description
Contaminated Mineral Oil	Used in most outdoor transformers and may have been contaminated from common industrial practices. PCB content is usually less than 1%.
Contaminated Retrofilling Fluids	Used to replace PCBs in transformer applications. Sometimes the new fluid becomes contaminated with residual amounts of PCB not removed by the original decontamination process.
Decontamination Flushings	Similar to the previous flushing, however PCB content is usually less than 1%.
Dredging Spoils	Sediments from streams, urban drains, or marine dredging. PCB concentration can be up to thousands of parts per million and may be largely associated with an organic component of the waste.
Large PCB Capacitors	Capacitors that contain more than 0.5 kg of PCBs. They range in size from a small book to a tall thin rectangular can up to 1 m in height with internal paper and metal foil immersed and thoroughly impregnated with PCBs.
Maintenance and Decommissioning Wastes	Similar to industrial waste from maintenance operations, includes small tools, rags, plastics, paper, sorbents and some free liquid (i.e. cleaning solvent contaminated with PCBs).
PCB Transformers, Hydraulic Equipment, Electromagnets, Heat Transfer Equipment, Vapour Diffusion Pumps	Large pieces of electrical/mechanical equipment that could be drained and/or decontaminated or complete units that still contain PCBs and/or PCB contaminated fluids.
Residues	Ash from incineration, organic sludge from sodium-based oil-decontamination processes, or solids from the decontamination of PCB equipment.
Small PCB Capacitors	Capacitors that contain less than 0.5 kg of PCBs. They may be associated with electronic or lighting equipment.
Soils	Solid wastes resulting from a spill cleanup and Demolition Spoils
Waste Oil	Used lubricating oils or other oils that have become contaminated with PCBs. Sludge may be present.
Construction and demolition waste (including European Waste codes list 17 04/17 05.17 07/17 09)	Construction and demolition wastes containing PCBs including PCB-containing resin floors, glazing units and capacitors.
Waste from manufacture, formulate, supply and use (MFSU) of paint and varnish including blasting abrasive (including European Waste codes 08 01/12 01)	Waste paint, varnish, paint sludge, aqueous sludge containing PCBs; Waste blasting material containing PCBs;
Municipal waste (including European Waste codes 20 01)	Municipal waste including electrical equipment for example fluorescent lamp ballasts containing PCBs;

Additional information on the management of PCBs is contained in the Intergovernmental Forum on Chemical Safety "Framework for the Management of PCBs." [43]

4.2.3 Identification and Characterisation of HCB Wastes

As was noted earlier, there are several potential sources of HCB. HCB can be generated as an impurity during the production of chlorinated solvents; an impurity in the synthesis of chlorinated pesticides; a trace contaminant in fugitive emission from the point of pesticide application; a by-product of chemical manufacturing; an ingredient in secondary aluminium processing; a by-product of waste incineration and open trash burning; etc. As a result, the method of identification is influenced by the source of HCB.

Identification options should include:

- an inventory of process wastes containing HCB in facilities that are involved in the production of chlorinated solvents, such as carbon tetrachloride, perchloroethylene, trichloroethylene, ethylene

dichloride, and 1,1,1-trichloroethane. It should be noted that carbon tetrachloride and 1,1,1-trichloroethane have been phased out in the developing world as “controlled substances” under the Montreal Protocol on Substances that Deplete the Ozone Layer (1987, and as subsequently amended and adjusted). Some of these facilities might have already been identified using mechanisms such as Canada’s National Pollutant Registry Inventory (NPRI); and the United States National Toxics Inventory and/or Toxics Release Inventory (TRI) and similar inventories in other developed countries;

- for HCBs contained in pesticides, municipalities could promote the collection of household and agricultural hazardous waste separate from other non-hazardous wastes. Not only will this result in the identification and collection of some of the banned POPs pesticides like DDT and aldrin, but it will also allow for the identification/collection of currently used pesticides that contain HCB. Such segregated hazardous waste collection systems are already in place in many EU countries and in North America; and
- an inventory of process wastes containing HCB in secondary aluminium foundries. Similar to facilities involved in the production of chlorinated solvents, some of these facilities might have already been identified using mechanisms such as Canada’s NPRI and the United States TRI and other similar inventories in developed countries.

4.2.4 Identification and Characterisation of Dioxin and Furan Wastes

PCDDs and PCDFs are not commercial chemical products but are trace level unintentional by-products of most forms of combustion and several industrial chemical processes. The concern is that dioxins and furans which are widely distributed throughout the environment in low concentrations, are toxic, persistent and bioaccumulative. Most people have detectable levels of dioxins and furans in their tissues. These levels, in the low parts per trillion, have accumulated over a lifetime and will persist for years, even if no additional exposure were to occur. This background exposure is likely to result in an increased risk of cancer and at or near those levels at which health effects are known to occur. The most potent dioxins, 2,3,7,8-TCDD, have been characterized by a number of national and international authorities, such as the International Agency for Research on Cancer and the U.S. EPA as a human carcinogen. The other 2,3,7,8-substituted dioxins and furans are regarded as likely human carcinogens.

Dioxins can be commonly detected in air, soil, sediments and food. Dioxins are transported primarily through the air and are deposited on the surfaces of soil, buildings and pavement, water bodies, and the leaves of plants. Most dioxins are introduced to the environment through the air as trace products of combustion. The principal route by which dioxins are introduced to most rivers, streams and lakes is soil erosion and storm water runoff from urban areas. Industrial discharges can significantly elevate water concentrations near the point of discharge to rivers and streams. Major contributors of dioxins/furans to the environment include:

- Incineration of municipal solid waste
- Incineration of medical and other hazardous wastes
- Secondary copper smelting
- Landfill fires
- Land application of sewage sludge
- Pesticide manufacture
- Cement kilns
- Coal fired power plants
- Residential wood burning
- Bleaching of wood pulp with elemental chlorine; and
- Backyard burning of household waste may also be an important source.

Governments need to take an active role in developing regulations, identification of sources, inventories and management of dioxins and furans unintentional production, reduction in emission limits and destruction of wastes. Some of the key steps are:

- Establish appropriate technical and management committees to develop the initial set of actions and reporting protocols;
- Ensure sufficient stakeholder and public involvement in the process;
- Ensure that appropriate socio-economic considerations are integrated into the standards and regulations being developed;
- Select priority sectors for development of emission limits based on release inventory;
- Establish work groups to address the selected priority sectors, including appropriate stakeholders;
- Identify opportunities for collaboration with other departments, governments and international agencies; and
- Establish committees on sectors of common interest to avoid duplication of effort and resources.

4.2.5 Typical Sampling Procedures

At times it will be necessary to collect POPs wastes samples and send them for analysis. The following sampling issues should be taken into consideration:

- The collection of samples of hazardous wastes for physical and/or chemical analysis is often a necessary task for assessing whether it is a POP pesticide waste and what level of concentrations of the contaminants are present. The samples have to be drawn using the protocol in place within the country. For countries that have no protocols it is recommended that they consult competent authorities in other member governments and or other regional/ international agencies to obtain relevant protocols.
- The dangerous nature of these substances, combined with potentially improper labelling and/or classification procedures, makes this task unique and more challenging than conventional environmental / chemical sampling.
- The basic objective of any sampling exercise is to produce a sample or set of samples representative of the source under investigation and suitable for subsequent analysis. Typically, in the case of wastes, the main goal is to identify the key hazard characteristics of the waste. This information may have to be used for:
 - assessing the extent of the hazard(s);
 - complying with regulatory standards; and
 - supporting future litigation.
- Typical questions asked in waste characterisation are:
 - Is this likely to be a waste?
 - What physical characteristics does it have?
 - What characteristics will this sample likely display?
 - Does the sample (and therefore the waste) display any hazard characteristics?
 - What compounds or contaminants are present?
 - Do these contaminants exceed any criteria or standards?
- Any sampling campaign will require a sampling plan – sample size, type of sample, number of samples, type of analysis, equipment requirements, method of sampling, do's and don'ts, sample storage and preservation, risk of exposure, emergency response, etc.
- No sampling should be conducted by untrained personnel. Personnel should be trained, prepared and must wear appropriate personnel protective equipment to do the sampling.
- During the time the samples are being analysed, the materials should be kept isolated and away from any potential routes for contamination. They should be kept well ventilated and marked clearly to ensure that no contact with people occurs.
- After the sample analyses are reviewed, decisions regarding the disposal or cleanup should be taken based on the regulatory guidelines of the country or the jurisdiction.

In the case of dioxins and furans, comprehensive advice can also be found in the “Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases” developed by UNEP Chemicals and currently updated under the auspices of the Stockholm Convention.

4.3 HANDLING, STORAGE AND TRANSPORTATION

The storage of POPs wastes, and its proper execution, involves a number of considerations and factors. In fact, the method of on-site POPs wastes storage or handling is important for the success or failure of the POPs wastes management programme. Proper planning from the initial stages of the programme is necessary to ensure success, reduced liability, and regulatory compliance.

4.3.1 Storage of POPs wastes in warehouses/sheds

There is a lack of uniformity in the development and adoption of waste regulations for the storage and handling of POPs wastes. For example, while many developed countries have adopted PCB/ hazardous waste regulations for the storage and handling of PCB wastes and have developed guidance documents for management of these, countries in Africa have expended considerable effort in establishing pesticide inventories, with significant less effort being placed on PCBs. Some key practices for storage of POPs include:

Minimum Design Requirements for Storage in Warehouses/sheds

The design of an appropriate warehouse/shed depends on the type of waste to be stored (PCBs, DDT, for example), the nature of the waste (liquid, solid, sludge, etc.), quantity (large vs. small), among other factors. However, there are some minimum design requirements that all storage facilities should adhere to. These include:

- a non-leaking roof;
- a raised floor;
- sidewalls capable of deflecting rain, etc.;
- protection from the elements, in general;
- appropriate containment for the material stored;
- protection from elevated temperatures to the extent practicable, through careful attention to siting, design and construction
- appropriate emergency apparatus such as sprinklers, fire extinguishers, as required; and
- adequate security to deter unauthorized access.

Storage of containers/ cartons containing POPs wastes

- the site for a new shed or warehouse should not be close to communities, hospitals, schools, shops, food markets and public areas; it should be well removed from water courses/ wells and not in a floodplain;
- the storage site should have easy access for loading/ unloading and for emergency vehicles from at least three sides of the building;
- the design capacity of the building should be generous and should avoid unnecessary stacking of the material;
- the storage site should be always secure and access should be restricted to authorized personnel to reduce exposure. Adequate notices should be posted to keep people informed of the contents and its potential danger;
- the containers should be stocked away from direct sunlight;
- the containers should be in good condition to prevent any release of their contents;
- in instances where original containers are in disrepair, repackaging is required;
- the facility should be well ventilated and well laid out for easy access;
- the storage facility should have at least 15 % to 20% free space for movement of fork lifts and other vehicles for stocking and dispensing;
- compatibility of materials kept in the areas is a key issue and other materials like waste acids/ bases etc. should be not stored along with pesticides and PCBs; liquids (PCBs) and solids (pesticides) should not be kept next to each other to prevent chemical reaction and

- contamination;
- stacked containers should be on pallets; corrosion resulting from rising damp or leaking chemicals should be promptly observed and dealt with appropriately.
- dust, granule and wet table powder formulations should be kept in cartons during storage to avoid caking;
- liquids should always be kept in banded areas with floor drain collection system;
- stacks should be arranged to minimise handling and to avoid damage during handling.
- floor spaces should be uncluttered, well marked and containers and cartons should be stacked at safe heights ensuring that they are stable; and
- emergency procedures should be available.

Storage of POP contaminated soils:

Contaminated soils containing POPs are likely to be received in bulk and would need storing until disposal options have been finalized. Key issues for soil storage include:

- keep the material secure (restricted access area);
- store under a roof to avoid direct sunlight and ensure that in case of rains/ washes, the water is collected and sent for treatment and does not contaminate watercourses;
- keep soils dry and well-ventilated; and
- post a notice in the surrounding area to ensure that people are aware of the contents.

4.3.2 Handling and transportation

Recommended procedures for POP wastes handling and transportation include:

- waste should be transported in dedicated trucks only;
- open and leaking containers of waste pesticides, PCBs, etc. should not be transported. Contents should be transferred or otherwise enclosed within another container before being transported;
- all loads should be securely fastened on the truck and all labels must be clearly readable;
- the truck should have in place appropriate placards and markings to indicate it is a hazardous cargo based on the regulatory requirements of the jurisdiction;
- the truck driver should be adequately trained to transport hazardous waste cargo and must have certification to prove this (as required by the jurisdictions);
- if there is an accident, the driver must be able to produce the manifest and emergency management procedures for the cargo to assist police/ fire personnel in dealing with the incident;
- the trucking company must be adequately insured (based on jurisdictional requirements) to handle any third party and environmental impairment liability claims in case of an accident;
- the loads should be periodically checked by a competent authority (e.g. during rest stops), to assure that the cargo is intact and there is not leakage;
- proper administrative and identification forms must accompany the truck and the material should be handed over appropriately at the receivers end; and
- the waste consignment must be carefully unloaded/ loaded from the truck [44].

4.3.3 Disposal of Pesticide Containers

Recommended procedures for handling and disposing of pesticide containers include:

- unless they are disposed of as toxic waste, empty containers should be cleaned to remove residual pesticides. Containers that are disposed as toxic waste do not need to be cleaned.
- containers should be cleaned by rinsing them several times with water, unless the label specifies that a different material (such as kerosene or diesel fuel) should be used;
- if containers are not clean after rinsing them with water, they can be washed out with other materials, such as a mixture of water, detergent and caustic soda;

- the washings should be collected for disposal in a safe environmentally sound manner at a central location authorized by the national authority;
- highly contaminated cardboard, paper and jute materials should be collected and sent to the central disposal centres along with other toxic waste; and
- glass containers should be smashed and steel drums and metal and plastic containers punctured and crushed (do not puncture aerosol containers) before being sent to a central location for disposal by the national authority.

The above discussions were focussed on issues relating to POPs waste identification, sampling, storage and transportation. These issues relating to identification and inventorisation of POPs are a challenge and need considerable attention of member countries in formulating appropriate regulatory regime and building capacity of stakeholders. Further discussion on potential disposal and containment technologies is presented in the next section.

5.0 TECHNOLOGIES FOR THE ENVIRONMENTALLY SOUND MANAGEMENT OF POPS WASTES

5.1 BACKGROUND

This chapter outlines technologies to be considered for the environmentally sound management of POPs wastes. The technologies presented include those for storage, containment, and destruction/irreversible transformation.

The destruction technologies/irreversible transformation includes off-site (where the wastes have to be transported to another location), as well as on-site (where wastes may be treated where the waste is generated) methods. Off-site technologies require the use of sophisticated treatment techniques that may, because of isolation, be more responsive to local health and environmental concerns. In line with the general obligations under the Basel Convention, wastes should be treated as close as possible to the point of generation. Movements and transport of POPs wastes increases the potential for occupational and public exposure based on the distance travelled and the number of people along the route.

5.2 MANAGEMENT OF POPS WASTES – REQUIREMENTS, CONCERNS, AND CRITERIA FOR PERFORMANCE AND EVALUATION

Following are some, but by no means all, of the requirements for the environmentally sound management of POPs wastes:

- Regulatory Requirements - The management of POPs wastes requires an effective regulatory regime covering all aspects of the waste cycle from generation to final disposition, either destruction/irreversible transformation or containment. Such a regime consists of a) legislation for the management of POPs wastes, encompassing identification, collection, storage, final disposal, b) procedures for monitoring and regulatory enforcement of all of these activities, and c) the financial and technical resources to ensure compliance.
- Inventories of POPs Stockpiles - The design and conduct of POPs wastes inventories are both complex and expensive. Many countries lack the necessary regulations to require inventories as well as the resources to undertake them. As a result, the full extent of the waste problem within most countries is probably unknown. The situation is further complicated if stockpiles contain not only the POPs prioritised under the Stockholm Convention but also other materials such as metal-containing pesticides, which may not be amenable to the technologies that are most appropriate for POPs.
- Collection, Storage and Containment - Where POPs wastes are strictly regulated and storage and containment requirements are monitored and enforced, the likelihood of deliberate and accidental releases to the environment is significantly reduced. A failure to implement proper storage

procedures could result in contamination of water, building structures, adjoining land, etc. at storage sites, thus increasing the extent of spread of contaminant and overall quantity of wastes and subsequently, potential for human and environmental harm. The method of collection, storage, and disposal of POPs wastes depends on the nature of the wastes, be they liquid, contaminated soil, metal components (e.g. PCB transformers and capacitors), sludge, ash, etc. Failure to implement appropriate management procedures can potentially lead to losses from existing stockpiles and the creation of new wastes due to cross-contamination or formation of by-products from inadequate disposal/destruction.

- **Transport** - There are inherent risks with waste transport. In particular, accidents resulting in spills or atmospheric releases, theft, etc., can divert wastes from their intended destination and thus, pose significant threats to humans and the environment. Workers involved in waste transport and emergency response teams are especially vulnerable to exposure during such occurrences and require proper training and equipment.
- **Efficacies of Management Technologies** - The Stockholm Convention requires that POPs waste be disposed of in such a way that the POPs content is “destroyed or irreversibly transformed so that they do not exhibit the characteristics of POPs, or otherwise be disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the persistent pollutant content is low”. Technologies that are potentially capable of meeting these criteria are generally very expensive and require highly skilled individuals for their management and operation. Further, some of the existing technologies, particularly those that are combustion-based, do not completely destroy the POP content in the targeted waste and may create new POPs such as dioxins, furans and HCB. Poorly designed landfills have been known to leach toxic chemicals into the groundwater, and to release noxious fumes. On the other hand, well-engineered landfills are much better containment facilities (see Section 5.5). Chemical treatment may produce a larger volume of less hazardous chemical wastes, which then require treatment and disposal.
- **Transboundary Movement of POPs Wastes** – There are contrary positions in the world on transboundary movement of POPs wastes for environmentally sound destruction or irreversible transformation. Some organizations are against movement of these wastes internationally and believe they should be dealt with in the country of origin. Others believe that in situations where they cannot be destroyed safely in the country where they are currently stockpiled, it is in the best interest of all if they are transported across national boundaries for disposal in an environmentally sound manner. In such case, it may be argued that the countries that have the capacity to deal with POPs waste in an environmentally sustainable manner have a responsibility to accept these wastes for destruction or irreversible transformation using the facilities and expertise at their disposal. However, the ESM requirements for various technologies have been highlighted but no recommendations regarding transboundary movement of POPs waste is proposed in these guidelines, beyond compliance with the Basel Convention.
- **Commercial and full-scale development of the technology** - The technologies discussed in the following sections are at differing stages of commercial and practical development. Some are well proven in long-term commercial full-scale operation, others have recently become commercially available, while still others are only developed to pilot scale or are still under early development.

5.3 TECHNOLOGIES FOR POPs WASTE MANAGEMENT

In a paper presented by four UNIDO scientists at the International Centre for Science (ICS-UNIDO) the following basic performance criteria for POPs waste technologies were listed: [45]

“The technologies used for destroying stockpiles of persistent organic pollutants (POPs) must meet the following fundamental performance criteria:

- **Destruction efficiencies of effectively almost 100 percent for the chemicals of concern:**
The determination of 100 percent destruction efficiency is necessarily based on findings of extremely low concentrations of the chemicals of concern, **approaching zero** in any and all residues, or outflow streams using the most sensitive analytical techniques available worldwide. As achieving absolute zero residues may be technically not feasible, the only possible criterion to set how low the required concentration must be, when considering toxic substances such as POPs, is the absence of any present and future harm to human health and the environment. Although expensive, complete analyses of all out flowing streams, residues, possible leaks must be carried out with a frequency sufficient to ensure compliance with this criterion during start-ups, shutdowns and routine operations.
- In order to better attain the abovementioned goal, priority is recommended for technologies that imply **containment of all residues and out flowing streams** for screening and, if necessary, reprocessing. This is to ensure that no chemicals of concern or other harmful compounds, such as newly formed POPs or other hazardous substances, are released to the environment. Technologies, which may require **uncontrolled releases** (e.g. relief valve from high-pressure vessels) or environmental spreading of POPs, even at hardly detectable levels (e.g. incineration processes with high gaseous mass flow released to atmosphere), should be carefully scrutinized and possibly avoided.”

Determining the extent to which a technology meets these criteria during both preliminary tests and routine operations depends on a variety of factors including, but not limited, to:

- scientific and engineering expertise;
- equipment and facilities for sampling and analysis of the materials to be destroyed and all residues of the destruction process;
- stringent operating guidelines; and
- comprehensive regulatory framework, including enforcement and monitoring requirements.”

Additional criteria for evaluating destruction technologies that have been suggested in a US Department of Energy report include: [46]

- capability of treating a variety of wastes with varying constituents with minimal pre-treatment of waste;
- secondary waste stream volumes that are significantly smaller than the original waste stream volumes and which contain no toxic reaction by-products;
- complete elimination of organic contaminants;
- off gas and secondary waste composition;
- cost; and
- risk.

Considering the various technologies available or under development for handling POPs wastes, it is important to distinguish between: (a) pre-treatment technologies that concentrate POPs in wastes so that the resulting pre-treated waste can be better subjected to a technology for sequestration or for destruction or irreversible transformation; (b) technologies that sequester the waste; and (c) technologies that actually achieve some measure of destruction or irreversible transformation. These guidelines consider the following technologies (not all of which are yet fully commercialized):

- **Technologies for destruction and/or irreversible transformation of POPs wastes**
 1. Incineration
 2. Gas-phase Chemical Reduction
 3. Electrochemical Oxidation
 4. Molten Materials Treatment (molten metals or salts)
 5. Solvated Electron Processes

6. Plasma Arc Processes
7. Base-catalyzed Decomposition
8. Catalytic Hydrogenation
9. Supercritical Water Oxidation
10. In-situ Vitrification

- **Technologies for sequestration of POPs wastes**

1. Engineered Landfills
2. Long-term Storage
3. Deep Well Injection

- **Pre-treatment technologies for concentration of POPs wastes**

1. Electro-osmosis
2. Thermal Desorption
3. Low Temperature Rinsing and Recovery of PCB Containing Materials

5.4 TECHNOLOGIES FOR THE DESTRUCTION AND/OR IRREVERSIBLE TRANSFORMATION OF POPS WASTES

Proper evaluation of technologies pursuant to selection of those most suitable for specific applications requires a clear understanding of the measures most commonly used to assess the extent to which technologies actually destroy and/or irreversibly transform the chemicals of concern. These measures – Destruction Efficiency (DE) and Destruction and Removal Efficiency (DRE) have been defined by UNIDO scientists as follows: [45]

- ***Destruction Efficiency (DE):*** *The overall destruction of a hazardous compound is calculated on the basis of total weight of the same into the process, minus the sum of the compound found in all products, by-products, and environmental releases, divided by the compound input. (DE is reported as a percentage).*
- ***Destruction and Removal Efficiency (DRE):*** *Destruction and removal efficiency is calculated as the efficiency in destruction and removal from a main stream, generally for flue gases. It is calculated similarly as the DE, but as it is referred only to one stream, which may be useful to evaluate cleaning equipment, but may be misleading for a whole process evaluation. For example, this measure may only take into account contaminants that are present in the stack gases (air emissions), ignoring contaminants released as solid and liquid residues. (e.g. bottom ash and waste water).*

It should be noted that a comparison of numerical values for DE or DRE is only meaningful in the context of a defined contaminant content in the input stream. Thus any technology can achieve a much higher numerical DE or DRE if the input stream contains a high percentage of the subject contaminant than if the input stream is dilute with respect to the contaminant. A lower achieved numerical DE or DRE in the case of dilute input streams is not necessarily an environmental deficit, as the actual burden of contaminant may be lower than the case of a higher DE or DRE applied to a more contaminated input stream. For example, the residual amount of contaminant arising from a DE of 99.9999% applied to one tonne of an input stream consisting 100% of contaminant X will be 1 gram. The same residual amount of contaminant will arise from an input stream containing only 1% of contaminant X even when the numerical DE is only 99.99%. This simple mathematical relationship is often forgotten and can lead to false comparisons between technologies.

If the obligations of the Stockholm Convention are to be met, it is evident that technologies for the destruction/irreversible transformation of POPs wastes are better evaluated according to their Destruction Efficiencies (DEs), rather than the more limited Destruction and Removal Efficiency (DRE).

5.4.1 Incineration

5.4.1.1 Hazardous Waste Incinerators

Incineration is a process involving the thermal oxidation of organic material through combustion. When used for mixed, radioactive, or hazardous waste treatment, incineration uses large volumes of air to provide the necessary combustion oxygen and the turbulence to effect complete heat transfer and mixing of waste and oxygen. Incineration processes can involve high temperatures and open flames, and require extensive off-gas treatment trains. [47]

Thermal oxidation units (incinerators) should be designed to handle the specific type(s) of waste to be treated. Properly designed incinerators can effectively remove volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), PCBs, pesticides, and petrochemicals from solid wastes such as contaminated soils. Incinerators can be designed to treat all types of wastes simultaneously or a single type. The four major subsystems in a thermal oxidation facility are (1) waste preparation and feed systems, (also known as pre-treatment), (2) combustion chambers, (3) air pollution control equipment, (also known as gas post treatment), and (4) liquids and ash handling (also known as solids post treatment), and residuals management systems. The combustion chamber could be a rotary kiln/dryer, thermal screw, fluidized bed, distillation chamber, or belt conveyor system (EPA 1993) [48]. An incinerator has one or two refractory lined combustion chambers operating at high enough temperatures to vaporize any organic compounds and destroy them (i.e. convert them to carbon dioxide, water, and acid gases such as hydrochloric acid vapours).

The three T's - time, temperature, and turbulence - are important for complete incineration of organic chemicals. For optimum combustion to occur, the volatilized or partially destructed organic chemicals need sufficient time at a high enough temperature and turbulence to thoroughly mix the off-gases with excess oxygen.

Incinerators come in a variety of designs. Some are small-scale fixed types, designed for specific users, local formulation plants, or for relatively small quantities of low hazard waste etc. Others may be specialized large-scale static units of various designs intended for the disposal of relatively large quantities of hazardous wastes. Still others can be fairly large mobile units with rotary kilns and air pollution control devices, such as bag-houses and scrubbers. These latter units can handle large amounts of liquid, solid and sludge waste, as well as contaminated soil.

Hazardous waste incinerators are commonly reported to achieve DREs of 99.9999¹%, but less is known about their Destruction Efficiencies (DEs). However, in one study of a hazardous waste incinerator, the Destruction Efficiencies (DEs) achieved by the incinerator were many times lower than the DREs, e.g., DEs of only 97.9 to 99.9 percent at the same time that DREs were 99.9998% and higher [49].

[NOTE: Should we include Greenpeace's modification (as appeared on pg. 17 of their detailed comments regarding the October 2002 draft) to the footnote here??]

¹ A DRE of 99.9999% is achievable, using best practice, when the waste being 'destroyed or irreversibly transformed' contains a high proportion of PCB contaminant. However, when the contaminant content is low (as in many wastes) the achievable DRE - expressed as a percentage - is less, even though this lower DRE will of course still result in a negligible residual contaminant content (given the low starting level). This is a simple mathematical consequence. As an example, 1 tonne of pure contaminant waste can be treated at a DRE of 99.9999% to result in a residual contaminant amount of 1 gram. However, for 1 tonne of a waste containing only 1% of contaminant then a lower DRE of 99.99% will still result in the same residual contaminant amount of 1 gram. In most circumstances the environmental measure we are interested in is not the numerical DRE, but "how much contaminant is left"? The use of numerical DREs - in isolation from other parameters - can be misleading and inappropriate as a control measure. This is not, of course, to deny the value of the DRE concept for comparing processes so long as the comparison is normalised to identical waste inputs.

Failure to ensure proper design, operation and maintenance of incinerators can result in health and environmental concerns due to increased formation of POPs by products such as dioxins and furans. Operators for these facilities need a high degree of training. The cost per unit of destruction is also extremely high for incineration so that destruction of POPs waste by incineration may not be economically viable in less wealthy countries. Final disposal of residues from incineration facilities require additional consideration and costs. Because of their toxic contents, incinerators flyash, slags and bottom ashes require further treatment, such as vitrification or solidification (cementation), followed by deposition in secured landfills.

Nevertheless, incineration is the most widely used and thus far best-proven technology for the destruction of PCBs. On a global scale enough capacity already exists to destroy all of the world's PCB wastes. While it is not a universal solution for the destruction of POPs wastes, at present it will usually be found to represent the BAT for most sites and for most waste streams.

[NOTE: Greenpeace's suggestion for insertion]

It is important to note that the Stockholm Convention identifies "waste incinerators, including co-incinerators of municipal, hazardous or medical waste or of sewage sludge" and "cement kilns firing hazardous waste" as industrial source categories of the by-product POPs – dioxins, furans, hexachlorobenzene and PCBs. Since all the POPs currently listed in the Stockholm Convention are classified as hazardous wastes in the Basel Convention, it can be concluded that incineration of POPs wastes in hazardous waste incinerators and cement kilns or other combustion facilities that co-fire wastes containing POPs has "the potential for comparatively high formation and release of these chemicals to the environment" as described in Annex C of the Stockholm Convention.]

5.4.1.2 Cement Kilns

Cement kilns are high temperature rotary kilns designed and constructed for the production of the clinker that is pulverized to make cement. Cement production is a highly energy-intensive process. Indeed, it is the largest industrial consumer of energy in some countries. This has led in recent years to a growing trend, particularly among the industrialized countries, of substituting various wastes for some portion of the conventional fuels used in cement production. Cement kiln operators in the United States, for example, have begun recovering energy from organic materials, including chlorinated compounds, as early as 1974. That practice has become commonplace by 1987. As a result, there exist within USEPA a large publicly available database concerning the environmental performance of cement kilns that recover energy from waste materials including POPs wastes. However, the United Nations FAO cautions that disposal of hazardous materials, such as obsolete pesticides, by burning in cement kilns is "*often not applicable in a safe and/or cost-effective manner*" [50]. In assessing the disposal of obsolete pesticides in cement kilns in developing countries, FAO recommended "*for the time being, to use this method only for liquid formulations of non-chlorinated pesticides,*" and further noted:

Most cement kilns in developing countries are not suitable for this purpose. Those models that are suitable can handle liquids. They cannot handle soils and contaminated materials. Incineration of powder formulations is possible but difficult. Liquids containing solid particles (crystals, precipitated emulsions) may cause problems. ... System process disturbances may cause toxic emissions. Long-term use for incineration of pesticides may cause environmental problems. There may be limits to the maximum chlorine content of products that can be incinerated [51].

FAO's cautions on the use of cement kilns for pesticide disposal in developing countries are lent considerable support by various steps, modifications made and problems encountered during the effort to dispose of 57,500 litres of 20% dinitro-o-cresol, a non-chlorinated pesticide, in a cement kiln in Tanzania [52]. For example, the specially designed waste introduction system suffered from leaks, blockages and other problems. The kiln "*broke down regularly during incineration of the DNOC*" due to problems with the kiln lining, power failures, feed disruptions, etc. According to his calculations, the cost of incinerating the pesticide in the cement kiln was US\$4,300 per tonne [52].

A review of test burns in eight cement kilns found DREs for a variety of chemicals ranging from 91.043 to 99.9999 percent, with an average DRE of 99.53 percent [53]. However, no information describing Destruction Efficiencies (DEs) was found. Some studies have found that, when hazardous waste is burned in cement kilns, dioxin releases in stack gases were increased 80-fold and dioxins in cement kiln dust were increased by 100-fold [54]. In the U.S., cement kilns burning hazardous waste are listed as the fifth largest source of dioxin emissions to the air, while those that do not burn hazardous wastes are the tenth largest source [54].

5.4.2 Gas Phase Chemical Reduction (GPCR)

This method involves hydrogen reacting with chlorinated organic compounds, at high temperatures, yielding primarily methane and hydrogen chloride. It has been successfully applied to various POPs wastes including PCBs, DDT, HCB, dioxins and furans. Destruction and removal efficiencies of GPCR are high, 99.99% (although this is generally lower than for well-operated incineration processes, which can achieve 99.9999%) and virtually all residues and emissions are captured for assay and reprocessing if needed². Traces of POPs will remain in the solid residues, as in the case of incineration technologies. The system can be constructed in either fixed or mobile configurations.

This process uses gas-phase reduction (using hydrogen) of chlorinated organic compounds at elevated temperatures to produce a hydrocarbon-rich gas stream. Typically it involves the gas-phase reduction of chlorinated hydrocarbons such as PCBs to methane and hydrogen chloride at 850°C. In some cases, wastes have to be pre-treated within a thermal desorption unit (TDU), which is operated in conjunction with the reduction reactor. The gas-phase reduction reaction takes place within a specially designed reactor at ambient pressure. Separate nozzles inject gaseous atomised waste, steam, and hydrogen into the reactor. As the mixture swirls down between the outer reactor wall and a central ceramic tube, it passes a series of electric "Glo-bar" heaters, raising the temperature to 850°C. The reduction reaction takes place as the gases enter the ceramic tube through inlets at the bottom of the tube and travel up toward the scrubber. The scrubber removes hydrogen chloride, heat, water, and particulate matter. If necessary, scrubber liquid may be recycled through the system for additional treatment.

For waste with a low organic content, the majority of the hydrogen-rich gas recirculates to the reactor; the remainder can be used as a supplementary fuel for a propane-fired boiler that produces steam. Processing waste with a high organic content produces excess gas product, which can be compressed and stored for later analysis and reuse as supplementary fuel.

The GPCR process have been used to treat a wide range of POPs and other chemical wastes at commercial scale, including PCBs (transformers, capacitors, liquids), DDT, mixed organochlorine pesticides, and dioxin/furan contaminated wastes. In commercial-scale performance tests, the gas-phase reduction process achieved DEs of 99.9999% and higher with high-strength PCB oils and chlorobenzenes, and 99.999 to 99.9999% with dioxins [55]. However, traces of POPs will remain in the solid residues, as in the case of incineration technologies.

5.4.3 Electrochemical Oxidation

Electrochemical oxidation plants have been designed for operation over a period of several years for specific waste streams. They are designed and installed in a modular form wherever possible, allowing offsite prefabrication, simplified installation, commissioning and decommissioning. Such plants are intended to be able to deal with all the waste streams associated with chemical contaminants. They are relatively simple, but remain expensive for POPs waste treatment.

² In commercial-scale performance tests in Canada, Des of 99.9999808 to 99.9999996 percent were achieved with PCBs and 99.9999836 to 99.9999972 percent with chlorobenzenes; for dioxins present as contaminants in the PCB oil, Des were 99.999 to 99.9999 percent. In regulatory testing in Japan, a DE of 99.99993 percent was achieved with dioxin-contaminated solid materials and 99.99999 percent with a liquid and granular solid mixture.

The process was first developed as a means of destroying organic wastes arising within the nuclear industry and for wastes arising from the decommissioning of stockpiles of chemical weapons. The technology has also been used on a small scale for the destruction of PCBs. The programme started in 1987 and led to the construction and operation of a 4 kW sized demonstration plant. Destruction of waste material is carried out by electro-chemical oxidation using highly reactive form of silver, (Ag^{++}) ions. The core of the process is a well-proven membrane electro-chemical cell of a sort widely used in the chemical (chlor-alkali) industry. The US Department of Energy believes this technology to be proven and ready to be commercialised for the destruction of a variety of organic materials [56].

The process is claimed to have the following key features: high recyclability of process chemicals; low waste stream volumes (gaseous, liquid and solid); no production of dioxins or dibenzofurans; all waste streams (gaseous, liquid and solid) may readily meet the requirements of the relevant environmental legislation; and liquid effluent streams consist only of dilute nitric acid (1% by weight), neutral mixed salt solutions or inorganic sodium salts. Destruction efficiencies are high and all residues and emissions are captured for assay and reprocessing, if needed. The technology has not been tested extensively for POPs destruction application.

This technology would be of great benefit if it can be developed and made mobile for developing countries so that the treatment plant could be transported to the waste source rather than transporting waste over long distances.

5.4.4 Molten Materials Processes

This technology uses a molten metal (sodium), a molten slag or a molten salt (generally sodium carbonate) to destroy pollutants. The descriptions of the three processes are as follows:

Molten Metal

The Molten Metal Process is also known as the Catalytic Extraction Process. This process uses a heated bath of molten metal to catalytically disrupt molecular bonds of contaminants and convert hazardous wastes into products of commercial value. The liquid metal acts as a catalyst and solvent in the dissociation of waste feed and synthesis of innocuous products. The molten metal causes the chemical compounds to break into their elements, which dissolve in the liquid metal solution. By adding selected co-reactants and controlling the reaction conditions, some of the dissolved elemental intermediates can be reacted to form desired products of commercial value [57].

Normally, the gaseous emissions contain synthesis gas, a mixture of carbon monoxide and hydrogen. This gaseous stream can be used as low NO_x fuel, or further separated to generate pure hydrogen, synthesis gas etc. The other by-product is typically a ceramic slag containing alumina, silica and sodium chloride. The slag can be usefully converted into industrial abrasives, construction materials or refractory base. Some low volatility metals are also released along with the gaseous emissions. These are trapped and recovered using a cold trap or high efficiency filter. [58]

The process operates under reducing conditions and as such is not conducive to formation of dioxins. Iron and nickel have been used as the metals for the metal baths [59].

Molten Slag

A molten slag system is used for treatment of liquids, sludges and metal-bearing wastes. In this process, the waste to be treated is blended with steelworks dust and fluxing agents, extracted, dried with heat from the furnace off-gases and fed into a foaming slag layer which forms at the top of the molten iron in an electric arc furnace at a temperature of around 1500 °C. The waste sinks into the slag phase, metal oxides are reduced to metals and all organic materials return to their basic elements, like in the molten metal process [58].

The destruction efficiency of this process is still to be confirmed especially for chlorinated organics and there is potential for volatilization of these organics if they do not dissolve in the molten slag. The formation of dioxins and other chlorinated organic materials cannot be discounted. There is still insufficient information on this technology. [58]

MOLTEN SALT

Molten Salt Oxidation (MSO) is a thermal means of completely oxidizing (destroying) the organic constituents of mixed and hazardous waste. The flameless reaction takes place at 700 to 950°C in a pool of benign salts, which is usually either sodium carbonate or a eutectic of alkali carbonates.

Oxidant air is added with the waste stream into the salt bath, and the reaction takes place within the salt bath virtually eliminating the fugitive inventories found in incineration. The organic components of the waste react with oxygen to produce CO₂, N₂, and water. Inorganics like halogens, sulphur and phosphorus are converted to acid gases, which are then “scrubbed” and trapped in the salt in forms such as NaCl and Na₂SO₄. Other incombustible inorganic constituents, heavy metals and radionuclides are held captive in the salt, either as metals or oxides, and are easily separated for disposal. The materials to be processed are normally conveyed into the oxidizing chambers using pneumatic feed systems and at times, solids have to be reduced to small particle sizes for pneumatic conveying. Liquid wastes are injected using commercial oil gun systems. The reaction product gases contain nitrogen, carbon dioxide, oxygen and steam, along with reaction salts, depending on the wastes [58].

Molten salt technology is not new. It was used approximately 20 years ago for coal gasification and its use for hazardous waste destruction was also demonstrated at that time. It has been used extensively for the past many years. Waste streams, which have low heating-value materials, such as soils, decontamination and decommissioning rubble, and high-water content streams, are by themselves not practical for treatment with MSO. Some wastes, such as aqueous streams, may be suitable if additional wastes with higher heat-contents are injected simultaneously [60].

MSO has several advantages over incineration. First, since MSO units operate at much lower temperatures, generation of NO_x is greatly reduced, as is the volatilization of heavy metals and radionuclides. Second, the generation of acid gas is eliminated since the acid gases (such as HCl, CO₂, etc.) are scrubbed by the alkaline carbonates, producing instead water (steam) and the corresponding salt. This eliminates the need for a wet-scrubber in the off-gas system. Third, the formation of secondary toxins (dioxins, furans, and other products of incomplete combustion) is less likely with MSO. In an incinerator, hot spots and feed in-homogeneities limit the process controllability. MSO provides a stable heat transfer medium with sufficient thermal mass/ inertia to resist thermal surges, ensuring temperature uniformity and provides increased and uniform contact time/residence time of the primary reactants, ensuring completeness of reaction. Lastly, less off-gas is generated in MSO because there is no fuel required to sustain or initiate a flame in this process. The off-gases from MSO are sent through standard dry off-gas cleanup equipment (bag filters or HEPA filters) to remove any remaining salt particles before undergoing gas analysis and release to the atmosphere, similar to the removal of fly ash from incinerator off-gas. [60]

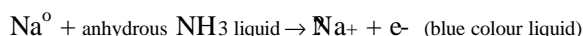
MSO units are more costly than incineration units. However, due to public pressure, existing incinerators are being scrutinized and are being forced to install more control and abatement devices. This increases incineration costs, narrowing the gap between the cost of the molten salt unit and incinerators. Since MSO is not an incineration process, it should gain better public acceptance than an incinerator [60].

Very high efficiencies (>99.9999%) are reported for liquid PCBs, PCB-containing solids, HCB, and chlordane. The process can accommodate organics with heavy metals. The operating costs are high and the system requires bag-houses for the metal/ particulate content in the off-gases. Sodium carbonate or alkali carbonate eutectics are the preferred salts. Materials like phosphorus, chlorine and sulphur are converted into inorganic salts and they are part of the salt overflow collected as waste. The process has been shown to be robust with very low risks of failure [60].

5.4.5 Solvated Electron Technology

The Solvated Electron Technology (SET) Process is a method of reducing halogenated hydrocarbons in a mixture of sodium or other alkali metal in liquid ammonia. Solvated electron technology is based on the fact that alkali metals – such as sodium - create a solvated electron solution when dissolved in liquid ammonia. As solvated (free) electrons are formed in the solution, they bond with the ions of contaminated materials to neutralize the hazardous constituents. The process is intended to destroy hazardous wastes and detoxify contaminated materials, including radioactive mixed waste, leaving the resultant material free for reuse or disposal.

In actual practice, pieces of anhydrous sodium or potassium are added to anhydrous liquid ammonia at about 100°C and the resulting colourless ammonia solution turns blue. The blue colour is due to the solvated electrons in the mixture. As sodium dissolves in ammonia it decomposes into sodium ions (Na⁺) and electrons (e⁻) as follows:



The solvated electrons in solution act as powerful reducing agents. This method can be used to strip chlorine atoms from small amounts of chlorocarbons, such as TCE, PCB, and DDD, DDE, DDT, dieldrin, and chlordane [61].

In practical application, contaminated materials are placed into a treatment cell and mixed with the solvated electron solution. In the case of PCBs or other halogenated pesticides, chemical reactions strip the halogen ions from the carbon ring. Other types of contaminants such as benzene or PAHs are also destroyed. At the end of the reaction, ammonia within the treatment cell is removed and recycled. As the solids are dried, the reaction products produced in the process precipitate into the solid matrix [62].

The technology does have some significant practical disadvantages. The stoichiometry of the chemical reactions involved means that relatively large quantities of molten sodium (or equivalent) are needed. Typically, for the destruction of 1 kg of PCBs the process will require 200-400 grams of metallic sodium. If the PCB material is not pure or dry the quantities of sodium required will increase significantly [62].

Operation of the process involves low temperatures (well below ambient) or elevated pressures. Handling metallic sodium requires recognition that it readily reacts explosively with water or moisture. Handling liquid ammonia requires recognition that it causes severe burns on skin contact and is highly toxic. For related safety reasons, the process also requires a thoroughly reliable and uninterruptible source of electric power to avoid unscheduled shutdowns with potential loss of containment. There are health and safety issues regarding the use of large quantities of ammonia and sodium at the site. This is analogous to operating a small chemical plant at the site and therefore would require an emergency response system and procedures in case of an accident or spills.

Since liquid ammonia is unable to penetrate wood or concrete, this technology cannot treat contaminants lodged in such materials. These materials will require crushing or shredding prior to treatment. Further, the reduction of halogenated materials from soils, oily wastes, sludge, and sediments requires almost complete removal of moisture through pre-drying. This is because liquid ammonia reacts quickly with water to form ammonium hydroxide, which is not only exothermic, but also inhibits production of solvated electrons. The sodium metal also has affinity for water to form sodium hydroxide that could result in the sodium not being fully available for contaminant destruction. Therefore, a precise qualitative analysis of the contaminants in the matrix is required before treating it with the SET process [63].

The SET process is one of the very few available technologies with demonstrated capability of treating PCBs in soils, sludges, and oils to less than 2 ppm. The technology is also effective in treating soils contaminated with pesticides. When evaluating options for a site that requires treatment to very low levels, SET could be considered as one of the viable alternatives [63].

5.4.6 Plasma Arc Systems

There are several technology suppliers for plasma arc processes. These processes utilize high temperatures (5,000 to 15,000°C), resulting from the conversion of electrical energy to heat, to produce a plasma. They involve passing a large electric current through an inert gas stream. Hazardous contaminants, such as PCBs, dioxins, furans, pesticides, etc., are broken into their atomic constituents, by injection into the plasma, or using the plasma as the heat source for combustion or pyrolysis. In many cases pre-treatment of wastes may be required. An off-gas treatment system depending on the type of wastes treated is required, and the residue is a vitrified solid or ash that can, in many cases, be landfilled. The process can handle organics and metals, and in its various types can destroy PCBs (including small-scale equipment) and HCB. The destruction efficiencies for this technology are quite high, >99.99%, but the process can be very complex and expensive and it is very operator intensive.

A sub-set of plasma arc technology is the DC plasma arc process that destroys dioxins and furans and vitrifies ashes to produce a high density, mechanically strong and environmentally stable product. The DC plasma arc treatment process is capable of handling both the incinerator-grate ash and the fly ash recovered from off-gas precipitators. The systems are designed to use either a twin-graphite electrode system or a single graphite electrode with conducting elements in the hearth for a return electrical path. The robust graphite electrode system provides high-temperature uniform heating that is stable in continuous operation and provides excellent environmental control. The cylindrical mild steel furnace shell is of welded construction, with extensive water cooled elements being employed at the slag line to reduce refractory wear. In the lower sidewall and furnace hearth, high thermal conductivity refractory bricks are used, designed to form a protective frozen slag at the hot face. The water-cooled furnace roof and upper sidewall sections are lined with a high grade refractory. The unit is sealed and operated at close to atmospheric pressure to prevent the ingress of air, or the egress of fume and dust. The feed material is metered to the furnace at a controlled rate and the plasma power is modulated to maintain the melt temperature at around 1500-1600°C. The molten slag overflows the furnace via a water-cooled spout where it is granulated or cast into ingots. The exhaust gases exiting the furnace pass through a secondary combustion chamber (SCC) to burn any residual flammable gases (i.e. CO and H₂). The gas is rapidly quenched using air drawn from the fugitive emissions control system. A dry scrubbing system is often used to remove acid gases contained in the off-gas prior to removal of the particulates in a fabric filter baghouse. The cleaned gas stream is vented to the atmosphere via the stack.

It is an established commercially viable technology. However, it is expensive and requires complex technical management. According to the U.S. National Research Council, waste streams from the plasma arc destruction of wastes are *“essentially the same as those from incineration.”*

5.4.7 Chemical Dehalogenation Processes (other than molten metal treatment)

Chemical dehalogenation removes halogens, including chlorine, from chemicals by hydrogen or a reducing radical containing a hydrogen donor. The term is also applied to dehalogenation by molten alkali metals, such as sodium, as described in Section 5.4.4 above.

5.4.7.1 Base-Catalysed Decomposition

This is a stand-alone destruction process in the same way that GPCR, SET, etc. are stand-alone processes. However, as with some of the other destruction technologies, certain wastes require the use of some separation technology, such as thermal desorption. With base-catalysed decomposition (BCD) processes, capture and treatment of residuals (volatilised contaminants captured, dust, and other condensates) may be difficult, especially when the soil contains high levels of fines and moisture.

5.4.7.1.1 Sodium bicarbonate

One version of a base-catalysed decomposition (BCD) process was developed by U.S. EPA's Risk Reduction Engineering Laboratory (RREL), in cooperation with the U.S. Naval Facilities Engineering

Services Center (NFESC) to remediate soils and sediments contaminated with chlorinated organic compounds, especially PCBs, dioxins, and furans. This version of the technology involves pre-treatment in a two-stage process that first removes chlorinated organics from soil and then destroys them by dechlorination. Contaminated soil is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate. The mixture is heated to about 350°C in a rotary reactor to volatilise the contaminants (Stage 1). The volatilised contaminants are captured, condensed, and treated (Stage 2) by reaction with sodium hydroxide and a hydrogen donor oil in the presence of a catalyst [64].

The following factors may limit the applicability and effectiveness of the process:

- High clay, humic material, or moisture content increases treatment costs;
- The organic contaminants volatilised in the Stage 1 (pre-treatment) reactor must be collected and treated in the Stage 2 (destruction) reactor;
- Process off-gas must be collected and treated;
- Process condensate must be collected and treated;
- Debris greater than 60 mm in diameter typically must be removed prior to processing [64].

5.4.7.2 Glycolate/Alkaline Polyethylene Glycol

This is a stand-alone destruction process in the same way that GPCR, SET, etc. are stand-alone processes. However, as with some of the other destruction technologies, certain wastes require the use of some separation technology, such as thermal desorption.

Another example of a base-catalysed decomposition technology is the so-called “Glycolate” process. This is a full-scale technology in which an alkaline polyethylene glycol (APEG) reagent, usually potassium polyethylene glycol (KPEG), is used. Contaminated soils and the reagent are mixed and heated in a treatment vessel. The APEG reagent dehalogenates the pollutant to form a glycol ether and/or other hydroxylated compound and an alkali metal salt, which is a water-soluble by-product. APEG dehalogenation is generally considered a stand-alone technology; however, it can be used in combination with other technologies. Treatment of the wastewater generated by the process may include chemical oxidation, biodegradation, carbon adsorption, or precipitation.

Factors that may limit the applicability and effectiveness of the process include:

- high clay and moisture content will increase treatment costs;
- the APEG/KPEG technology is generally not cost-effective for large waste volumes; and
- concentrations of chlorinated organics greater than 5% require large volumes of reagent;

While the costs of this technology may be less than incineration (because of lower energy costs at lower process temperatures) concerns remain regarding the formation of toxic by-products (such as dioxins and furans), both in air and as solid wastes sometimes remain.

5.4.8 Catalytic Hydrogenation

[To be developed]

5.4.9 Supercritical Water Oxidation

[To be developed]

5.4.10 In-situ Vitrification

In-situ vitrification (ISV) is a process which uses electrical power to heat and melt soil contaminated with organics, inorganics, and metal-bearing wastes. The molten material cools to form a hard, monolithic, chemically inert, stable glass and crystalline product that incorporates the inorganic compounds and heavy metals in the hazardous waste. The organic contaminants within the waste are vapourized or pyrolyzed and migrate to the surface of the vitrified zone where they are oxidized under a collection hood. Residual emissions are captured in an off-gas treatment system [66].

One implementation of ISV uses four electrodes that are inserted into the ground to the desired treatment depth. A conductive mixture of flaked graphite and glass frit is placed among the electrodes to act as a starter path. Electrical power is charged to the electrodes, which establishes an electrical current in the soil through the starter path. The resultant power heats the starter path and surrounding soil to 2,000°C, which is well above the initial melting temperature of typical soils. The graphite starter is consumed by oxidation, and the current is transferred to the soil, which is electrically conductive in the molten state. The molten mass continues to grow downward and outward until the melt zone reaches the desired depth and width. The process is repeated in square arrays until the desired volume of soil has been vitrified. With favourable site conditions, it is estimated that a processing depth of up to 10 m can be achieved. An off-gas collection hood covers the processing area. An air stream is fed through the hood to provide excess oxygen for combustion of pyrolysis products and organic vapours. The off-gases, combustion products, and air are drawn from the hood into the off-gas treatment system by a draft blower [66].

Possible emissions resulting from in-situ vitrification include steam from the contact of the melt with saturated soil if the treated soil is wet. This steam release can cause dangerous splattering of molten glass. The main release to land is the vitrified soil itself. Past analysis has shown the vitrified soil to be devoid of residual organics. It typically passes the USEPA's TCLP test criteria for priority pollutant metals [67].

This technology is used to treat soil, dewatered sludge, mine tailings, buried wastes, and sediments contaminated with organic, inorganic, and metal wastes. Generally, organic contaminants at concentrations in the 5 to 10 weight percent range and inorganic contaminants at concentrations in the 5 to 15 weight percent range are expected to be acceptable for ISV treatment [66].

This is a high temperature thermal process that incorporates electric melting of contaminated soils, sludges, etc. to destroy the organic components such as pesticides, herbicides, HCB, PCBs, and dioxins. Destruction and removal efficiencies greater 99.999% have been reported for PCBs [49]. High concentrations of organics, contained in the contaminated soils, can be destroyed by this process, leaving the inorganics, metals in a vitrified product. Vitrification provides high volume reduction of wastes with little or no secondary production of new wastes. Levels of dioxins/furans in off-gases have met regulatory limits.

There is much less experience in utilizing this technology compared to that with hazardous waste incineration. Production and release of dioxins and furans is a possibility and the process is recommended for adoption unless careful monitoring of the process is not assured.

5.5 TECHNOLOGIES FOR THE SEQUESTRATION OF POPS WASTES

5.5.1 Engineered Landfills

Landfilling is a method of containment and disposal, rather than of destruction. Article 6(1)(d)(ii) of the POPs Convention allows for parties to assess whether certain POPs wastes should be "... disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the persistent organic pollutant content is low..." This section of the report, in conjunction with existing Basel Convention's Technical Guidelines on Specially Engineered Landfills, attempts to discuss the basic principles of environmentally sound disposal in a well-engineered landfill. [70]

In the developed countries certain types of wastes, such as contaminated building materials, low concentration residues, incineration ash, low-level radioactive POPs wastes or low concentration soils and sediments can be disposed of in a landfill equipped with appropriate liners, containment systems, groundwater monitoring and leachate collection. In developing countries, because of costs and lack of well-engineered landfills POPs wastes should not, in many cases, be disposed of in landfills [70].

A distinction also needs to be drawn between the characteristics of, and the regulations governing, landfills for 'normal' wastes and specialised landfills for 'hazardous wastes' (including wastes containing or

contaminated with POPs). In developing countries, more extensive use is made of landfills, and the distinction between the landfilling of hazardous and non-hazardous wastes may become blurred.

The landfill site selection process is very important, as areas with significant rainfall and high groundwater table, porous soils, etc. may render the site unsuitable. Subsurface water flow/gradient patterns should be clearly defined. Landfills have to be well located, designed to high standards of safety and operated under strict conditions to ensure that the remnant wastes that are disposed at the landfill, do not leach into the ground or surface water. Further, the landfill operator should provide closure and post-closure monitoring of the landfill.

It is important to recognize that landfilling does not lessen toxicity, mobility, or volume of hazardous wastes, but can, in well-designed landfills, mitigate migration. Because landfill liners eventually leak, it is inevitable that leachate, including POPs which are leached from landfilled materials, will migrate through the liners and may pollute the underlying groundwater. Landfill caps are most effective where most of the underlying waste is above the water table. A cap, by itself, cannot prevent the horizontal flow of ground water through the waste, only the vertical entry of water into the waste. In many cases landfill caps are used in conjunction with engineered and vertical walls to minimize horizontal flow and migration. The effective life of landfill components (including caps) can be extended by long-term inspection and maintenance. Vegetation, which has a tendency for deep root penetration, should not be allowed to grow on the cap. In addition, precautions must be taken to assume that the integrity of the cap is not compromised by land use activities.

POPs such as PCBs, have been found to escape from landfills by volatilizing into the surrounding air. PCBs and other semivolatile contaminants are known to evaporate more rapidly with increased moisture in soils and sediments and with increased relative humidity in the air.

5.5.2 Long-Term Storage

In cases where jurisdictions lack any environmentally sound mechanism for disposal, long-term storage could be an option. Long-term storage is designed to maintain the POPs wastes in a safe and retrievable form until an affordable, safe and permanent solution is found.

Secure storage technology is currently used for storage of other hazardous materials, such as used nuclear fuel rods. Storage sites with appropriate construction, security, monitoring could be designed to keep the waste secure and away from human contact and environmental degradation. These types of solutions may be too costly and sophisticated for developing countries, but some less secure form of long-term storage may be possible in these locations and does have the advantage of bringing all waste to a common location.

The suitability and availability of long-term storage sites will depend critically on local geological conditions and may not be a readily available option in some countries, e.g. small island states. Less costly form of storage may be expedient in these locations, taking into account the local climatic conditions.

5.5.3 Deep Well Injection

Deep well injection is a liquid waste disposal technology which uses injection wells to place treated or untreated liquid waste into a geologic formation that has no potential future use and that will not allow future migration of contaminants into potential potable water aquifers.

A typical injection well consists of concentric pipes, which can extend up to a thousand metres or more down from the surface level into highly saline, permeable injection zones that are confined vertically by impermeable strata. The outermost pipe or surface casing, extends below the base of any underground sources of drinking water (USDW) and is cemented back to the surface to prevent contamination of the USDW. Directly inside the surface casing is a long string casing that extends to and sometimes into the injection zone. This casing is filled in with cement all the way back to the surface in order to seal off the injected waste from the formations above the injection zone back to the surface. The casing provides a seal

between the wastes in the injection zone and the upper formations. The waste is injected through the injection tubing inside the long string casing either through perforation in the long string or in the open hole below the bottom of the long string. The space between the string casing and the injection tube, called the annulus, is filled with an inert, pressurized fluid, and is sealed at the bottom by a removable packer preventing injected wastewater from backing up into the annulus.

Even though deep well injection is one of the disposal options in Annex IVA of the Basel Convention (D3 operation), this is not considered as an environmentally sound management method for POPs wastes as there are no satisfactory control to prevent possible leaking of wastes into the environment, and retrieval of wastes for further treatment and destruction are impossible.

Other factors that limit the applicability and effectiveness of this process include:

- This method is totally unsuitable for untreated POPs liquid wastes. Only treated liquids containing extremely low level of POPs wastes may be permitted after extensive assessment of the geology of the region based on local regulatory regime. *“Low level POPs wastes are yet undefined by the POPs Convention Signatories and the Basel Parties.”*
- Injection should not be used for hazardous waste disposal in any areas where seismic activity could potentially occur;
- Injected wastes must be compatible with the mechanical components of the injection well system and the natural formation water. The waste generator may be required to perform physical, chemical, biological, or thermal treatment for removal of various contaminants or constituents from the waste to modify the physical and chemical character of the waste to assure compatibility;
- Corrosive media may react with the injection well components, with injection zone formation, or with confining strata with very undesirable results. Wastes should be neutralized;
- Organic carbon may serve as an energy source for indigenous or injected bacteria resulting in rapid population growth and subsequent fouling;
- Waste streams containing organic contaminants above their solubility limits may require pre-treatment before injection into a well;
- Site assessment and aquifer characterization are required to determine suitability of site for injection;
- Many countries do not have suitable geological formations for the proper deep well injection of low level POPs wastes; and
- Extensive assessments must be completed prior to receiving approval from regulatory authorities.

5.6 PRE-TREATMENT TECHNOLOGIES FOR THE CONCENTRATION OF POPs WASTES

5.6.1 Electro-osmosis

This pre-treatment process uses electrokinetics to move contaminants in soil pore water into treatment zones where the contaminants can be captured or decomposed. The process is especially suited to sites with low - permeability soils, where electro-osmosis can move water faster and more uniformly than hydraulic methods, and with very low power consumption. Both vertical and horizontal configurations have been conceptualised, but fieldwork to date is more advanced for the vertical configurations. Some key requirements of the technology include:

- electrodes are energized by direct current, which causes the water and soluble contaminants to move into or through the treatment layers and also heats the soil;
- treatment zones contain reagents that decompose the soluble organic contaminants or adsorb contaminants for immobilisation or subsequent removal and disposal; and
- a water management system recycles the water that accumulates at the cathode (high pH) back to the anode (low pH) for acid-base neutralisation. Alternatively, electrode polarity can be reversed periodically to reverse electro osmotic flow and neutralize pH.

Factors that may limit the applicability and effectiveness of the process include:

- the need for a water management system to neutralize pH near the cathode and anode; and
- chloride ions in the groundwater can be converted to chlorine at the anode, resulting in the formation of trihalomethanes.

Electro-osmosis has been used as a means of concentrating wastes prior to their destruction by bioremediation technologies. It has thus far been applied only to soluble semi-volatile and volatile halogenated organics. The contaminants in soil pore water are moved into treatment zones, which contain reagents to decompose the organics, or to be captured or adsorbed for subsequent removal and disposal.

The supplier expects operating costs to be low due to low power usage and equipment requirements. However, this technology is complex with combinations of different types of techniques and no information on capital costs is available. It may require increased levels of monitoring and control to receive community acceptance.

5.6.2 Thermal Desorption

Thermal desorption, in its many variations, involves the volatilisation of water and organics in non-halogenated and semi-volatile organic compounds by heating them to temperatures up to 800°C. The gases can be collected and suitable treatment such as by afterburner, condenser or carbon beds, depending on the compounds, can then be applied. The targets of this technology include a range of organochlorine pesticide and PCB contaminated soils and sludges. It is not considered suitable for liquids. When subjecting materials containing these POPs to thermal desorption, it is important to note that the formation of by-products POPs, such as dioxins and furans, occurs across a relatively broad temperature range, the optimum window of formation for dioxins and furans of 300-400 °C.

A specific application of thermal desorption is as a pre-treatment prior to destruction of organo-chlorine wastes by base-catalysed decomposition (Section 5.4.7.1).

In most instances the use of thermal desorption technology is coupled with incineration (afterburners) in order to achieve destruction of the POPs content (Section 5.4.1). Some desorber designs can also decontaminate small amounts of sediment or liquid waste in conjunction with solid waste.

5.6.3 Low-temperature Rinsing and Materials Recovery for electrical equipment contaminated with PCBs

This technology decontaminates equipment containing-PCBs through a multi-stage rinsing process with progressive dismantling of the equipment. The PCBs are separated from the solid, inorganic parts of the equipment (copper, metallic sheets of the transformers core, casings), with the liquid PCB being subsequently destroyed, for instance by one of the processes listed in Section 5.4.

Typically, the main steps of the process are dissolving, rinsing (at about 100 °C, with six times exchange of the solvent), dismantling of the equipment, fractional distillation of the solvent and purification of the abovementioned metallic compounds. Tetrachloroethene (perchloroethylene) is used as solvent in a closed loop system. The whole treatment lasts about 30 hours.

The technology achieves the recovery of up to 95% of the solids of a transformer. All metallic components of the equipment are being recovered as secondary raw materials with a residual contamination of approximately 2 ppm. In the case of capacitors, the metallic content and degree of recovery is lower.

Since all treatment of the equipment occurs at temperatures below 100°C, the intrinsic risk of creation of polychlorinated dioxins and furans is avoided. The low processing temperatures allow recovery of the metallic components. The decontaminated metal sheets of the transformer core, for instance, can be used for manufacturing new, smaller transformers.

The entire cleaning process is handled in a closed-circuit system, avoiding all noxious emissions into the environment. It is a commercially viable and easily manageable technology. It can be adopted and implemented worldwide, provided that proper training of the operating staff and technical supervision can be ensured.

5.7 OTHER TECHNOLOGIES

5.7.1 Bioremediation

Bioremediation technologies utilize indigenous or inoculated micro-organisms including fungi, bacteria and other microbes, to degrade organic contaminants found in soil and/or ground water, converting them to harmless end products. In some instances, non-indigenous microbes are also added to help break down the wastes. This technique can be applied to treat halogenated and non-halogenated volatile and semi-volatile organics including a number of pesticides. The strain of microbes used is generally specific to the wastes to be destroyed. Some examples of species capable of breaking down POPs are as follows [69]:

- DDT: *Pseudomonas aeruginosa*
- Dioxins: Mutant Strains of *Pseudomonas*;
- HCB/ PCB/ TCDD: *Saccharomyces cerevisiae*.

Under aerobic conditions, the microorganisms will convert many organic contaminants to carbon dioxide, water and microbial cell mass. Under anaerobic conditions, the organic contaminants are metabolised to methane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas.

Complete process trains including bioreactors, filters, land farming/treatment and other equipment can be included to suit the type of wastes and the location. Generally, the treatment times are long when compared to other technologies such as incineration or gas-phase chemical reduction. The rate of the remediation depends on soil type, rainfall, temperature, concentrations and types of wastes and microbes. In addition, the mixing equipment and duration of mixing steps are determined to be critical for the efficiency of this technology. Field demonstration conducted on a Superfund³ site in Tampa, Florida using a composting process resulted in an overall destruction rate of 90% for chlordane, DDT, dieldrin and toxaphene.

The costs involved in applying this technology are dependent on whether the wastes are to be moved to another site for treatment or can be treated on site (in-situ). The process can be simple, unless the procedure is carried out using complex processes involving bioreactors and other equipment requiring skilled process operators. The addition of in-vessel treatment can add the dimension of higher maintenance, while speeding up the process.

There is considerable experience around the world on using bioremediation developed over the past two to three decades. Variants of this technology may in the future be applicable, but need to be evaluated on a site-specific and technology-specific basis given the wide range of bioremediation processes. Unfortunately little information is available on the achievable destruction efficiencies (DEs) performance for specific POPs wastes.

A problem specific to the use of bioremediation for the treatment of POPs wastes is that POPs are, by definition, highly resistant to biodegradation. That is not to say that bioremediation is impossible, but the number of species and strains of organisms (typically micro-organisms) that can be applied is much smaller than for other wastes. Considerable research is ongoing to develop suitable strains of microorganism and some progress is claimed.

³ Superfund refers to the USEPA Programme to remediate contaminated sites throughout the U.S. The Superfund Amendments and Reauthorization Act (SARA) amended the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) on October 17, 1986. SARA reflected U.S. EPA's experience in administering the complex Superfund program during its first six years and made several important changes and additions to the program.

5.7.2 Phytoremediation

This is an emerging variant of bioremediation technology that uses various plants to remove, transfer, stabilize or render harmless contaminants in soil and sediment. It can potentially be used for the clean-up of organic solvents, pesticide and PCB wastes. However, not all pollutants can be remediated equally, and plant residues may need to be disposed of as hazardous wastes. As for other forms of bioremediation, POPs wastes are particularly resistant to biodegradation and the number of available species for phytoremediation is small.

Phytoremediation applications can be classified according to the contaminant fate and the mechanisms involved. Such mechanisms include extraction of contaminants from soil or ground water by plant roots and translocation/accumulation of contaminants into plant shoots and leaves (phyto-extraction); degradation of contaminants within plant tissues by biotic and abiotic processes (phyto-degradation); volatilisation or transpiration of volatile contaminants from plants to air; immobilisation of contaminants at the interface of roots and soil (phyto-stabilisation); hydraulic control of ground water (plume control); and control of runoff, erosion, and infiltration by vegetative covers.

The costs of this treatment method are low, as only basic agricultural practices are required to implement the technology. However, the time -period for any remediation might be quite long, and there is still the potential for remnant concentrations of contaminants. However, phytoremediation technology is developed with species of plants that are site specific and requires extensive monitoring and verification to ensure that the results are being achieved. To date bioremediation methods cannot be assigned to be environmentally sound methods for disposal of wastes containing POPs due to insufficient efficacy and efficiency. However, on grounds of their low costs they may become the only feasible alternative in some cases, e.g. for remediation of large soil areas of low POP contamination.

5.7.3 Technologies Under Development

Some of the other destruction technologies that are under development or in limited use, for certain specific types of wastes, include: activated carbon adsorption, ion exchange, ultraviolet radiation, ozonolysis, ultraviolet radiation, oxidation with ozone and/or hydrogen peroxide, solar detoxification, concentrated solar flux, and fluidised bed systems.

It is hoped that over time advances will be made in both in discovering new technologies and in implementing the older technologies more easily and with improved destruction efficiencies and reduced costs.

5.8 SELECTION OF ENVIRONMENTALLY SOUND DISPOSAL METHODS

The selection of the appropriate technology for a particular type of POPs waste at a particular location offers distinct challenges. Some typical forms of POPs wastes include:

- “pure” POPs solids, e.g. obsolete pesticide stocks;
- “pure” POPs liquids, e.g. PCB liquids and heavily contaminated oils;
- POPs contaminated liquids, e.g. oils with low levels of PCBs, liquid residues from equipment cleaning and flushing;
- POPs contaminated structures/ equipments, e.g. transformers/ capacitors;
- POPs contaminated containers, e.g. drums/ barrels, etc.
- POPs contaminated soils/ sediments;
- POPs contaminated building materials; and
- POPs contaminated residues, e.g. fly ash, bottom slag, etc.

The selection of appropriate technology anywhere in the world involves the consideration of issues including:

- nature of the POPs wastes concerned;
- quantity and location of the POPs waste concerned;
- available technology options;
- transportation and permitting issues;
- economics;
- capacity of the local operators to operate the technology safely; and
- capacity of the local operators to operate the technology at its optimum destruction and removal efficiency.

A typical technology appropriateness chart is presented in Table 5.1, which takes into consideration the quantity of material involved, the type of waste and the potential of the technology to destroy the POPs contaminant efficiently. It also discusses the various steps that might be required to ensure environmentally sound disposal.

Based on the evaluation of various technologies and their capability to destroy POPs as well as considering the requirements of destruction under the Stockholm Convention, the following observations are presented:

- the necessary levels of destruction (DE) and irreversible transformation should be in the order of 99.999% + as the best of the technologies commercially available are capable of achieving this level of destruction either on their own or in combination, when properly applied;
- no significant amount of new POPs should be released to the environment during destruction/irreversible transformation of POPs wastes;
- the technologies presented in the Table 5.1 range from very simple to extremely complicated and expensive, and includes technologies that are currently being pilot tested. The amount of operator training also varies from simple to extensive;
- it has to be recognised, however, that even the best technologies will not achieve their full potential in every case. The actual performance of a given technology will depend critically on the nature of the waste stream and the circumstances prevailing at a particular site (including the nature of the available management and operational skills, the availability of reliable services – including power and waste services, etc. The concept of best available techniques (BAT) takes account of this inherent variability in performance and is well suited to the choice of technology for the disposal of POPs wastes;
- the environmentally sound disposal of POPs wastes is a complex issue – encompassing in it the concept of both sustainability and environmentally friendly nature of the disposal methodologies. At the heart of this concept is to ensure that the disposal is acceptable technically and socially (short and long-term health and economic impacts);
- the economics of the disposal process itself can be a limitation for many countries. While one process may be affordable in one region and this may not be the case in another; therefore caution must be taken to avoid over generalization in developing disposal criterion or evaluating disposal technologies; and
- in view of the above, the following alternative criteria for POPs wastes disposal technologies may be considered for evaluation and categorization of these waste technologies:
 - A1 – Destruction efficiencies of effectively 100%, e.g., 99.9999% or greater;
 - A2 – No formation of dioxins, furans and other by-product POPs;
 - A3 - No releases of dioxins/furans and other by-product POPs; and
 - A4 - No process residues (gaseous, liquid and/or solid) containing POPs or having POPs characteristics.

5.9 OPPORTUNITIES FOR 3R'S (REUSE, RECOVER AND RECYCLE)

The Stockholm Convention (§6.1(d)(iii)) prohibits the use of disposal operations that may lead to recovery, recycling, reclamation, direct reuse or alternative uses of POPs. Therefore, suitable technologies for POPs as wastes must be geared to the destruction of these wastes. However, the potential for metal recycling does exist with PCB wastes once the metallic components of the waste have been decontaminated. Liquid PCBs can be removed from equipment to allow safe disposal or recycling of the solid components. Chemical dechlorination processes are designed to allow the reuse/recycling of chlorine free oil. They can be used to decontaminate mineral oil containing PCBs. The decontaminated PCB-free mineral oil can be re-used. The decontaminated solids/metal, such as transformer hulks, hydraulic equipment, and heat exchange equipment can then be recycled in conventional metal plants, such as metal foundries [43, 68].

Incineration technology may, under some circumstances, allow the recovery of some of the heat of combustion and/or of the chlorine content of wastes as useful transformation products (including anhydrous hydrogen chloride and/or aqueous hydrochloric acid) reducing the need for *de novo* production of these chemicals.

**TABLE 5.1
TECHNOLOGY APPLICABILITY AND ESM REQUIREMENTS**

Types of Wastes

- A. “pure” POP solids – e.g obsolete pesticide stocks;
- B1. “pure” POP liquid – e.g PCB contaminated oils;
- B2. POP contaminated liquids – e.g flushing liquids, etc.
- C. POP contaminated structures/ equipments – transformers/ capacitors; POP contaminated containers – drums/ barrels etc.
- D. POP contaminated soils/ sediments;
- E. POP contaminated building materials; and
- F. POP contaminated residues – e.g fly ash, bottoms slag etc.;

Technology Type	Capability to handle the waste types	Conditions necessary to make the disposal qualify for environmentally sound management	Efficiency of Destruction/ irreversible Transformation and Limitations	Comments
Incineration	A, B, C, D, E, F	<p>1 Fixed Rotary Kiln Incinerator with secondary burner, quench tower and pollution control and monitoring system.</p> <p>2 Certified and approved design to ensure proper residence time, operating temperatures, air turbulence, secondary burner and automatically monitoring of exhaust flue gas.</p> <p>3 Training of operators and plant personnel for proper operations.</p> <p>4 Process for on-going independent verification of operation statistics to ensure agreed BAT destruction and removal efficiencies on a pre-agreed schedule.</p> <p>5 Availability of a certified wastewater treatment facility.</p> <p>6 Availability of approved engineered hazardous waste landfill.</p>	<p>Thermal destruction – 99.9999%(normalized to 100% POPs input stream) possible.</p> <p>Need facility to treat/ precipitate residues and contaminant in wastewater.</p> <p>Need appropriate authorized landfill to deposit fly ash / residue.</p>	<p>A well-defined technology capable of handling varying types of wastes with varying concentration and varying containers. This reduces a lot of handling issues.</p> <p>There is potential to form dioxins and furans in the process if incorrectly operated.</p>
Gas Phase Chemical Reduction	A, B C, D, E, F – Some preprocessing may be required.	<p>1 Certified and approved design to ensure that the facility meets with local regulatory requirements.</p> <p>2 Training of operators and plant personnel for proper operations.</p> <p>3 Process for on-going independent verification of</p>	<p>Fairly high – 99.999%+ DE (based on 100% POPs input stream) has been cited in one reference – but typical DRE values are 99.99%</p> <p>Arsenic/ Sulphur contaminates the catalyst and there is a need to monitor this – and to</p>	<p>Units have performed satisfactorily over a prolonged period of time and are a viable alternative to incineration.</p> <p>It is preferred that the unit be skid mounted and made easily portable so as to reduce waste</p>

Technology Type	Capability to handle the waste types	Conditions necessary to make the disposal qualify for environmentally sound management	Efficiency of Destruction/ irreversible Transformation and Limitations	Comments
		operation statistics to ensure agreed destruction and removal efficiencies on a pre-agreed schedule.	apply appropriate pre-treatment techniques where necessary - to ensure efficiencies are maintained. Limited number of installations. Safety concerns about handling hydrogen gas at high temperatures and pressures – especially in developing countries lacking chemical industry experience.	transportation over long distances. However, there is potential to form dioxins and furans in the process if incorrectly operated.
Electrochemical Oxidation	A, B, E	1 Certified and approved design to ensure that the facility meets with local regulatory requirements. 2 Training of operators and plant personnel for proper operations. 3 Process for on-going independent verification of operation statistics to ensure agreed destruction efficiencies on a pre-agreed schedule. 4 Availability of a certified wastewater treatment facility.	High – 99.99%+ (normalized to 100% POPs input stream) Proven Commercially – but not for all Stockholm Convention POPs as yet. Limited number of installations.	Experience on POPs is limited and need more case studies to support broader implementation.
Molten Materials Process	A, B, E	1 Certified and approved design to ensure that the facility meets with local regulatory requirements. 2 Training of operators and plant personnel for proper operations. 3 Process for on-going independent verification of operation statistics to ensure destruction efficiencies of over 99.99% on a pre-agreed schedule. 4 Off gases – pollution monitoring required and secondary treatment facility required.	Fairly high – 99.99 to 99.9999 (normalized to 100% POPs input stream) Solid and gaseous residues require treatment like incineration. Major safety issues involved in handling liquid metallic sodium.	Molten salt process: Well established and as it works in reducing environment, has little potential to generate dioxins and furans. Still needs further development for commercial applications. Molten slag process: Process has still to be established. Has potential for volatilization of POPs. Molten salt process: Well established and tested process. High efficiencies and in some cases may offer advantages over incineration and are

Technology Type	Capability to handle the waste types	Conditions necessary to make the disposal qualify for environmentally sound management	Efficiency of Destruction/irreversible Transformation and Limitations	Comments
				likely to get better community acceptance where there are resistance against incineration. However, molten salt oxidation (MSO) units are more costly than incineration units, and can present safety issues requiring careful management and supervision.
Solvated Electron Technology (SET)	A, B, C, D, E	<p>1 Certified and approved design to ensure that the facility meets with local regulatory requirements.</p> <p>2 Training of operators and plant personnel for proper operations.</p> <p>3 Process for on-going independent verification of operation statistics to ensure agreed destruction efficiencies on a pre-agreed schedule.</p> <p>4 Solid waste management facility required.</p>	<p>High – 99.999%+ (normalized to 100% POPs input)</p> <p>Major safety issues involved in handling metallic sodium and anhydrous liquid ammonia.</p>	Operational technology. Operates at low temperatures (requiring cryogenic experience with liquid ammonia) or at elevated pressures. Reduced threat of dioxin/furan formation. It has potential for adoption for POPs wastes treatment as an alternative to traditional technologies.
Plasma Arc Systems	A, D, E	<p>1 Certified and approved design to ensure that the facility meets with local regulatory requirements.</p> <p>2 Training of operators and plant personnel for proper operations.</p> <p>3 Process for on-going independent verification of operation statistics to ensure agreed destruction efficiencies on a pre-agreed schedule.</p> <p>4 Solid management facility required.</p>	<p>High – 99.99%+ (normalized to 100% POPs input)</p> <p>Complex technology.</p> <p>Expensive.</p>	<p>Commercialised process but not many facilities exist. Has good potential. Needs landfilling of vitrified product and requires off gas management.</p> <p>Particularly suitable in countries having suitable redundant equipment from space programs (e.g. the countries of the former Soviet Union).</p>
Base-catalysed Decomposition (BCD)	A, E	<p>1 Specially engineered facility with appropriate equipment and trained personnel.</p> <p>2 Availability of experts to advise on chemical addition, treatment and monitoring.</p> <p>3 Availability of a certified wastewater treatment facility.</p> <p>4 Availability of approved</p>	<p>Destruction efficiencies vary – moderate 80% to 95%.</p> <p>Not extremely reliable as it needs expert supervision.</p> <p>Good only for small quantities of waste.</p>	This process will generate high volume of low toxic waste that has to be disposed off.

Technology Type	Capability to handle the waste types	Conditions necessary to make the disposal qualify for environmentally sound management	Efficiency of Destruction/irreversible Transformation and Limitations	Comments
Engineered Landfills	E, F, G	<p>engineered hazardous waste landfill.</p> <p>1 Certified and approved landfill facility.</p> <p>2 Well designed and operated facility to international standards with stabilization prior to placing sludges.</p> <p>3 Has in place leachate monitoring, collection and treatment system.</p> <p>4 Regulatory framework in place for long term monitoring and post-closure liability.</p>	<p>Sequestration rather than disposal.</p> <p>Long term liability issues but good for very low concentration* waste.</p> <p>Relatively low costs of operation if well designed and operated.</p> <p>*not yet defined and needs discussion among Parties to the Convention.</p>	<p>Landfill is a requirement in all jurisdictions and it is preferable that the Convention creates a uniform design, operating, closure and post closure guidelines for implementation throughout the member countries.</p>
Long-term storage	A, B, C, D, E, F, G		Sequestration rather than disposal	May be justified in cases where storage may allow later disposal by a better technology than currently available.
Deep Well Injection	None of the above directly. Low concentration liquid waste may be acceptable in certain jurisdictions for deep well injection.	Difficult to establish ESM norms.	Sequestration rather than disposal; Not much control on its potential to damage the groundwater;	Not generally accepted but is practiced in certain jurisdictions after extensive geomorphological/hydrogeological investigation.
Electro-osmosis	E	<p>1 Specially engineered facility with appropriate equipment and trained personnel.</p> <p>2 Availability of experts to advice on treatment and monitoring.</p> <p>3 Need off gas monitoring and management.</p>	<p>Pre-treatment rather than disposal</p> <p>High – 99.9999%+ [based on 100% POPs input stream]</p> <p>Complex technology and limited use data.</p> <p>Concern with regard to the formation of trihalomethanes and other chlorine compounds in the water.</p>	<p>Not fully developed and more information is needed to comment on its suitability.</p> <p>May be useful in some cases as a pre-treatment prior to bioremediation</p>
Thermal Desorption	A, E		Pre-treatment rather than disposal	May sometimes be of value as a pre-treatment

Technology Type	Capability to handle the waste types	Conditions necessary to make the disposal qualify for environmentally sound management	Efficiency of Destruction/ irreversible Transformation and Limitations	Comments
				prior to destruction methods such as base-catalysed decomposition or incineration.
PCB Low Temperature Rinsing and Materials Recovery	B1,C	<p>1 Specially engineered facility with appropriate equipment and trained personnel.</p> <p>2 Availability of experts to advice on treatment and monitoring.</p> <p>3 Need for monitoring and management of the equipment/ materials post processing to ensure the efficacy and efficiency of the system.</p>	<p>Benefits of the low-temperature rinsing and materials recovery technology:</p> <ul style="list-style-type: none"> - low treatment temperatures, eliminating any dioxin risk - low complexity - recovery of up to 95% of the solid parts of a transformers after decontamination - easily scaleable to suit the needs of developing countries - commercially viable and well-established. 	<p>Commercially available and being used in Germany;</p> <p>Can be implemented in the developing country under supervision and training of experienced operations staff.</p>
Bioremediation	E	<p>1 Specially tested strains of micro-organism with extensive lab testing and regulatory approvals – both for in-situ and ex-situ uses. Strains of micro-organism available are particularly limited for POPs, which are by definition resistant to biodegradation.</p> <p>2 Training of field personnel for monitoring and management.</p> <p>3 Process for on-going independent verification of operation statistics to ensure high destruction efficiencies on a pre-agreed schedule.</p> <p>4 Arrangements for disposal of solid mass.</p>	<p>Medium to high</p> <p>Not suitable for all types of contaminants and need selective development of strains of microorganism for typical local climatic conditions;</p> <p>Not easy to implement.</p>	<p>Threshold concentration of contaminants for application of this methodology would need to be specified, as it may not be suitable for high concentration of POPs. Not a generic solution.</p> <p>Has been applied in conjunction with electro-osmotic pre-treatment.</p>
Phytoremediation	E	<p>Not enough information to specify EMS requirements.</p> <p>Species of plant available are particularly limited for POPs, which are by definition resistant to biodegradation.</p>	<p>Medium to high.</p> <p>Uncertain results.</p>	<p>A subset of bioremediation.</p> <p>Not proven extensively. Technology needs to be developed locally for specific problems. High learning curve.</p>

6.0 ESTABLISHING APPROPRIATE CONCENTRATION LEVELS

Article 6.2 of the Stockholm Convention requires its “Conference of the Parties to cooperate closely with the appropriate bodies of the Basel Convention ...to, inter alia, ...

“establish levels of destruction and irreversible transformation necessary to ensure that the characteristics of persistent organic pollutants as specified in paragraph 1 of Annex D are not exhibited; and ... work to establish, as appropriate, the concentration levels of the chemicals listed in Annexes A, B and C in order to define the low persistent organic pollutant content referred to in paragraph 1(d)(ii).”

The determination of concentrations to establish low levels of POPs will be a complex process and it is likely to be impossible to develop quantitative guidelines of universal applicability.

It is theoretically possible to calculate risk-based acceptable concentrations. However, as the first step in deriving acceptable concentrations is to determine an acceptable risk, such approaches may prove highly controversial. A few jurisdictions (e.g. US EPA) have used 1×10^{-6} and some have used 1×10^{-5} (e.g. Health Canada) to represent acceptable level of risk for carcinogens during the lifetime of a human being. Other regulators and other interest groups have considered these levels either too high or too low. The potential exposure pathways for members of the public must also be a consideration in the calculation of an acceptable concentration for determining the risk.

The methodology that might be adopted could be to study the exposure pathway of POPs in either water or soil and assess the extent of exposure and subsequently the risk to a farmer through the soil or the community through drinking water. The level of acceptable risk can then be back calculated to give a concentration of the particular POPs concentration in the medium – water or soil. However, as already pointed out, the level of acceptability and the threshold concentration of the particular POPs based on its toxicity studies have to be agreed upon by the group of experts of the Basel Convention before this task can be accomplished. Another input required from these experts would be on the potential use of representative ecological receptors (sentinel species) as indicators for establishing acceptable low levels.

An important consideration in the determination of low or acceptable concentrations of POPs is the detection limits of these compounds. Environment Canada has reported that analysis of concentrations of individual congeners (variants) of PCBs, dioxins, or furans are difficult but well developed. The detection of extremely low levels of POPs, however, requires highly sophisticated analytical techniques and instruments.

Unfortunately, these are often either expensive or not available in many countries. Analytical costs for POPs are frequently two or more orders of magnitude greater than those for common pollutants, such as sulphur oxides and nitrogen oxides. These costs are a significant barrier to improving society’s understanding of the effects of these substances in the environment. Nonetheless, techniques available for the identification and analysis of POPs have advanced significantly through the past decade. Future advance may reduce the cost of analysis (3). However, the sensitivity of current analytical methods is so great that it is likely that POPs (particularly those such as dioxins and furans that have diffuse as well as point, and natural as well as anthropogenic, sources) will be detected at trace levels in virtually all samples.

Unfortunately, these kinds of approaches, although science-based, would be very difficult to apply in practical situations – above all in developing countries – and would be both time-consuming and costly. Furthermore, the techniques would in practice require a considerable number of assumptions and approximations to be made, the choice of which might prove controversial.

An alternative approach to quantitative risk assessment would rely on existing regulations. Thus, for example, the 1989 "Canadian Council of the Ministers of the Environment (CCME) - Guidelines for the Management of PCB Wastes" defines a PCB waste as any PCB liquid, PCB solid or PCB equipment containing more than 50 parts per million PCB that have been taken out of service for the purpose of disposal. Therefore, a waste with less than 50 ppm PCB could be inferred to be having a low concentration. However, there may be difficulty in gaining international acceptance for national or regional regulatory

standards that may be of limited applicability under the circumstances prevailing in other countries or regions.

A more generally acceptable approach to determining concentration levels of POPs that represent 'low POP content' in the context of Article 6 §1(d)(ii) of the Stockholm Convention may be to make use of the concept of 'best available techniques' (BAT) as is in any case required for Annex C substances under Article 5 of that Convention. The concept of BAT is already defined in some detail in Part V.B of Annex C to the Convention and is being further elaborated under the Convention by a BAT/BEP working group established by the Intergovernmental Negotiating Committee (INC) of the Convention. This approach focuses on the practical considerations of what has to be done and what can be achieved in terms of environmental protection than on a mechanical 'one size fits all' approach that would be hard to apply across all POPs (including possible future POPs) and all countries.

The appropriate bodies of the Basel and Stockholm Conventions could usefully cooperate closely in developing the concept of BAT as it applies to the destruction and/or irreversible transformation of POPs as wastes. These Technical Guidelines could become a description of BAT, and could usefully indicate the levels of destruction and removal that are possible under optimal conditions. These levels could then become indicators of achievable 'low POPs content' in treated or untreated wastes that would allow for their disposal 'in an environmentally sound manner other than destruction or irreversible transformation' in the context of Article 6 §1(d)(ii) of the Stockholm Convention. This approach would have the advantage that the designation of 'low POPs content' would take account of the technological capabilities at the relevant site as well as of the physical, chemical, toxicological and environmental properties of the individual POP (or POPs) concerned.

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