

Updated general technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (POPs)

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Abbreviations and acronyms

AOAC	Association of Official Analytical Chemists
ASE	accelerated solvent extraction
ASTM	American Society for Testing and Materials
BAT	best available techniques
BCD	base-catalysed decomposition
BEP	best environmental practices
CD	catalytic dechlorination
CEN	European Committee for Standardization
CFCs	chlorofluorocarbons
CHD	catalytic hydrodechlorination
CSIRO	Commonwealth Scientific Industrial Research Organization (Australia)
DDT	1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane (dichlorodiphenyltrichloroethane)
DE	destruction efficiency
DRE	destruction removal efficiency
ECD	electron capture detector
EOX	acetone petroleum ether extractable organohalogen
EPA	Environmental Protection Agency (United States of America)
ESM	environmentally sound management
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FRTR	Federal Remediation Technologies Roundtable (United States of America)
GEMS	Global Environment Monitoring System
GEF	Global Environment Facility
GPCR	gas-phase chemical reduction
HASP	health and safety plan
HCB	hexachlorobenzene
HRGC	high-resolution gas chromatography
HRMS	high-resolution mass spectrometry
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
IPA	isopropyl alcohol
IPCS	International Programme on Chemical Safety
ISO	International Organization for Standardization
LRMS	low-resolution mass spectrometry
LTTD	low-temperature thermal desorption
LWPS	liquid waste pre-heater system
MSD	mass-selective detectors
NFM	non-ferrous metal
NIP	national implementation plan
OCP	organochlorine pesticide
OECD	Organisation for Economic Co-operation and Development
OEWG	Open-ended Working Group of the Basel Convention
PAH	polycyclic aromatic hydrocarbon
PBB	polybrominated biphenyl
PCB	polychlorinated biphenyl
PCD	photochemical dechlorination
PCDD	polychlorinated dibenzo-p-dioxin
PCDF	polychlorinated dibenzo-furan
PCT	polychlorinated terphenyl
Pd/C	palladium on carbon
POP	persistent organic pollutant
QA	quality assurance
QC	quality control
SCWO	supercritical water oxidation
SOP	standard operational procedure
t-BuOK	potassium tert-butoxide
TEQ	toxic equivalent
TRBP	thermal reduction batch processor
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
WHO	World Health Organization

Units of measurement

ng/kg	nanogram(s) per kilogram. Corresponds to parts per trillion (ppt) by mass.
µg/kg	microgram(s) per kilogram. Corresponds to parts per billion (ppb) by mass.
mg/kg	milligram(s) per kilogram. Corresponds to parts per million (ppm) by mass.
ng	nanogram
mg	milligram
kg	kilogram
Mg	megagram (1,000 kg or 1 tonne)
Nm ³	normal cubic metre; refers to dry gas, 101.3 kPa and 273.15 K
kW	kilowatt
kWh	kilowatt-hour
MJ	megajoule
million	10 ⁶
billion	10 ⁹
trillion	10 ¹²
ppm	parts per million
ppb	parts per billion
ppt	parts per trillion

I. Introduction

A. Scope

1. The present general technical guidelines provide guidance for the environmentally sound management (ESM) of wastes consisting of, containing or contaminated with persistent organic pollutants (POPs), pursuant to decisions IV/17, V/26, VI/23, VII/13 and VIII/16 of the Conference of the Parties to the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal, I/4, II/10, III/8, IV/11 and V/12 of the Open-ended Working Group of the Basel Convention, resolution 5 of the Conference of Plenipotentiaries to the Stockholm Convention on Persistent Organic Pollutants, decisions INC-6/5 and INC-7/6 of the Intergovernmental Negotiating Committee for an International Legally Binding Instrument for Implementing Action on Certain Persistent Organic Pollutants and decisions SC-1/21 and SC-2/6 of the Conference of the Parties to the Stockholm Convention.

2. Specific technical guidelines on wastes consisting of, containing or contaminated with the following categories of POPs have been developed:

(a) Polychlorinated biphenyls (PCBs); this technical guideline also covers polychlorinated terphenyls (PCTs) and polybrominated biphenyls (PBBs), which are subject to the Basel Convention but are not POPs subject to the Stockholm Convention;

(b) The pesticide POPs aldrin, chlordane, dieldrin, endrin, heptachlor, hexachlorobenzene (HCB),¹ mirex and toxaphene, and HCB as an industrial chemical;

(c) 1,1,1-Trichloro-2,2-bis(4-chlorophenyl)ethane (DDT);

(d) Unintentionally produced polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), HCB and PCBs.

3. The guidance provided within this document is intended to serve as a stand-alone general guidance and also as what might be termed an “umbrella” guide to be used in conjunction with the specific technical guidelines.

4. To these ends, the present general technical guidelines provide:

(a) General guidance on the management of wastes consisting of, containing or contaminated with POPs; and

(b) A framework for addressing issues referred to in Article 6, paragraph 2 of the Stockholm Convention (see subsection II.B.2 of the present guidelines on waste-related provisions of the Stockholm Convention).

5. Considerations pertaining to the environmentally sound disposal of wastes consisting of, containing or contaminated with POPs discussed in these guidelines include pre-treatment since it may be important when determining the disposal method. The guidelines also provide guidance on reducing or eliminating releases to the environment from waste disposal and treatment processes.

6. It should be noted that guidance on best available techniques (BAT) and best environmental practices (BEP) as they apply to the prevention or minimization of the formation and release of unintentional POPs from the anthropogenic sources listed in Annex C of the Stockholm Convention is provided by the Stockholm Convention. It should also be noted that there are draft guidelines on best available techniques and provisional guidance on best environmental practices relevant to Article 5 and Annex C of the Stockholm Convention on Persistent Organic Pollutants. Those guidelines were finalized by the Stockholm Convention Expert Group on Best Available Techniques and Best Environmental Practices in November 2006. A final version of the guidelines is expected to be adopted by the Conference of the Parties of the Stockholm Convention at its third meeting, in 2007.

¹ HCB features three times in the list to reflect its status as an industrial chemical, a pesticide (fungicide) and an unintentionally produced POP.

B. About POPs²

7. Most of the quantities of POPs are of anthropogenic origin. For some POPs, such as those listed in Annex C of the Stockholm Convention, some quantities are also generated by natural processes.
8. The characteristics of POPs (toxicity, persistence and bioaccumulation), the potential for their long-range transport, and their ubiquitous presence throughout the world in ecosystems and in humans were the impetus for the creation of the Stockholm Convention. As well, as noted in chapter II, section A, subsection 2 below, wastes consisting of, containing or contaminated with POPs are listed as wastes in Annexes I and VIII of the Basel Convention.
9. Improper treatment or disposal of a waste consisting of, containing or contaminated with POPs can lead to releases of POPs. Some disposal technologies can also lead to the unintentional formation and release of POPs.

II. Relevant provisions of the Basel and Stockholm conventions

10. In addition to the Basel and Stockholm conventions there are other international instruments related to POPs. These are listed in annex I below.

A. Basel Convention

1. General provisions

11. The Basel Convention, which entered into force on 5 May 1992, stipulates that any transboundary movement of wastes (export, import, or transit) is permitted only when the movement itself and the disposal of the concerned hazardous or other wastes are environmentally sound.
12. In its Article 2 (“Definitions”), paragraph 1, the Basel Convention defines wastes as “substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law”. In paragraph 4 of that Article, it defines disposal as “any operation specified in Annex IV” to the Convention. In paragraph 8, it defines the environmentally sound management of hazardous wastes or other wastes 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”.
13. Article 4 (“General obligations”), paragraph 1, establishes the procedure by which Parties exercising their right to prohibit the import of hazardous wastes or other wastes for disposal shall inform the other Parties of their decision. Paragraph 1 (a) states: “Parties exercising their right to prohibit the import of hazardous or other wastes for disposal shall inform the other Parties of their decision pursuant to Article 13.” Paragraph 1 (b) states: “Parties shall prohibit or shall not permit the export of hazardous or other wastes to the Parties which have prohibited the import of such waste when notified pursuant to subparagraph (a).”
14. Article 4, paragraphs 2 (a)–(d), contains key provisions of the Basel Convention pertaining to ESM, waste minimization, and waste disposal practices that mitigate adverse effects on human health and the environment:

“Each Party shall take appropriate measures to:

 - (a) Ensure that the generation of hazardous wastes and other wastes within it is reduced to a minimum, taking into account social, technological and economic aspects;
 - (b) Ensure the availability of adequate disposal facilities, for the environmentally sound management of hazardous wastes and other wastes, that shall be located, to the extent possible, within it, whatever the place of their disposal;
 - (c) Ensure that persons involved in the management of hazardous wastes or other wastes within it take such steps as are necessary to prevent pollution due to hazardous wastes and other wastes arising from such management and, if such pollution occurs, to minimize the consequences thereof for human health and the environment;

² Further information on the characteristics of POPs is available from several sources, including the Agency for Toxic Substances and Disease Registry, Global Programme of Action for the Protection of the Marine Environment from Land-based Activities, and the World Health Organization International Programme on Chemical Safety (1995) (see annex V “Bibliography” below).

(d) Ensure that the transboundary movement of hazardous wastes and other wastes is reduced to the minimum consistent with the environmentally sound and efficient management of such wastes, and is conducted in a manner which will protect human health and the environment against the adverse effects which may result from such movement”.

2. POPs-related provisions

15. Article 1 (“Scope of the Convention”) defines the waste types subject to the Basel Convention. Subparagraph (a) of that Article sets forth a two-step process for determining whether a “waste” is a “hazardous waste” subject to the Convention: first, the waste must belong to any category contained in Annex I to the Convention (“Categories of wastes to be controlled”), and second, the waste must possess at least one of the characteristics listed in Annex III to the Convention (“List of hazardous characteristics”).

16. Examples of Annex I wastes which may consist of, contain or be contaminated with POPs include:

- Y2 Wastes from the production and preparation of pharmaceutical products
- Y3 Waste pharmaceuticals, drugs and medicines
- Y4 Wastes from the production, formulation and use of biocides and phytopharmaceuticals
- Y5 Wastes from the manufacture, formulation and use of wood preserving chemicals
- Y6 Wastes from the production, formulation and use of organic solvents
- Y7 Wastes from heat treatment and tempering operations containing cyanides
- Y8 Waste mineral oils unfit for their originally intended use
- Y9 Waste oils/water, hydrocarbons/water mixtures, emulsions
- Y10 Waste substances and articles containing or contaminated with polychlorinated biphenyls (PCBs) and/or polychlorinated terphenyls (PCTs) and/or polybrominated biphenyls (PBBs)
- Y11 Waste tarry residues arising from refining, distillation and any pyrolytic treatment
- Y12 Wastes from production, formulation and use of inks, dyes, pigments, paints, lacquers, varnish
- Y13 Wastes from production, formulation and use of resins, latex, plasticizers, glues/adhesives
- Y14 Waste chemical substances arising from research and development or teaching activities which are not identified and/or are new and whose effects on man and/or the environment are not known
- Y16 Wastes from production, formulation and use of photographic chemicals and processing materials
- Y17 Wastes resulting from surface treatment of metals and plastics
- Y18 Residues arising from industrial waste disposal operations
- Y39 Phenols; phenol compounds including chlorophenols
- Y40 Ethers
- Y41 Halogenated organic solvents
- Y42 Organic solvents excluding halogenated solvents
- Y43 Any congener of polychlorinated dibenzo-furan
- Y44 Any congener of polychlorinated dibenzo-p-dioxin
- Y45 Organohalogen compounds other than substances referred to in this Annex (e.g., Y39, Y41, Y42, Y43, Y44)

17. PCDDs and PCDFs, for example, can be formed unintentionally during the manufacture of chlorophenols, which have been used in the preservation of wood, paints and glues, as well as during the manufacture of other industrial chemicals and pesticides. PCDDs and PCDFs can also be found in slags and fly ashes produced during industrial waste disposal operations. Several of the pesticide POPs have been or are being used as biocides. PCBs have been widely used in the past in paint additives, adhesives and plastics. HCB has been used as an intermediate or additive in various manufacturing processes, including the production of synthetic rubber, pyrotechnics and ammunition, dyes and pentachlorophenol. In addition, both PCBs and HCB are known to be formed through the same processes that create PCDDs and PCDFs.

18. Annex I wastes are presumed to exhibit one or more Annex III hazard characteristics, which may include H11 “Toxic (delayed or chronic)”, H12 “Ecotoxic” and H6.1 “Poisonous (acute)”, unless, through “national tests”, they can be shown not to exhibit such characteristics. National tests may be useful for identifying a particular hazard characteristic listed in Annex III until such time as the hazardous characteristic is fully defined. Guidance papers for each Annex III hazard characteristic are currently being developed under the Basel Convention.

19. List A of Annex VIII of the Convention describes wastes that are “characterized as hazardous under Article 1 paragraph 1 (a) of this Convention” although “Designation of a waste on Annex VIII does not preclude the use of Annex III (hazard characteristics) to demonstrate that a waste is not hazardous” (Annex I, paragraph (b)). List B of Annex IX lists wastes which “will not be wastes covered by Article 1, paragraph 1 (a), of this Convention unless they contain Annex I material to an extent causing them to exhibit an Annex III characteristic”. The following Annex VIII waste characteristics in particular are applicable to POPs:

(a) PCBs, PCTs and PBBs

A1180 Waste electrical and electronic assemblies or scrap³ containing components such as accumulators and other batteries included on list A, mercury-switches, glass from cathode-ray tubes and other activated glass and PCB-capacitors, or contaminated with Annex I constituents (e.g., cadmium, mercury, lead, polychlorinated biphenyl) to an extent that they possess any of the characteristics contained in Annex III (note the related entry on list B B1110)⁴

A3180 Wastes, substances and articles containing, consisting of or contaminated with polychlorinated biphenyl (PCB), polychlorinated terphenyl (PCT), polychlorinated naphthalene (PCN) or polybrominated biphenyl (PBB), or any other polybrominated analogues of these compounds, at a concentration level of 50 mg/kg or more⁵

(b) Pesticide POPs, including aldrin, chlordane, DDT, dieldrin, endrin, HCB, heptachlor, mirex and toxaphene

A4030 Wastes from the production, formulation and use of biocides and phytopharmaceuticals, including waste pesticides and herbicides, which are off-specification, outdated⁶, or unfit for their originally intended use

(c) PCDDs and PCDFs

A4110 Wastes that contain, consist of or are contaminated with any of the following:

- Any congener of polychlorinated dibenzofuran
- Any congener of polychlorinated dibenzodioxin

³ This entry does not include scrap assemblies from electric power generation.

⁴ PCBs are at a concentration level of 50 mg/kg or more.

⁵ The 50 mg/kg level is considered to be an internationally practical level for all wastes. However, many individual countries have established lower regulatory levels (e.g., 20 mg/kg) for specific wastes.

⁶ Outdated means unused within the period recommended by the manufacturer.

20. List A of Annex VIII includes a number of wastes or waste categories that have the potential to contain or be contaminated with POPs, including:

- A1090 Ashes from the incineration of insulated copper wire
- A1100 Dusts and residues from gas cleaning systems of copper smelters
- A2040 Waste gypsum arising from chemical industry processes, when containing Annex I constituents to the extent that it exhibits an Annex III hazardous characteristic (note the related entry on list B B2080)
- A2060 Coal-fired power plant fly ash containing Annex I substances in concentrations sufficient to exhibit Annex III characteristics (note the related entry on list B B2050)
- A3020 Waste mineral oils unfit for their originally intended use
- A3040 Waste thermal (heat transfer) fluids
- A3050 Wastes from production, formulation and use of resins, latex, plasticizers, glue/adhesives excluding such wastes specified on list B (note the related entry on list B B4020)
- A3070 Waste phenols; phenol compounds including chlorophenol in the form of liquids or sludges
- A 3090 Waste leather dust, ash, sludges and flours when containing hexavalent chromium compounds or biocides (note the related entry on list B B3100)
- A3100 Waste paring and other waste of leather or of composition leather not suitable for the manufacture of leather articles containing hexavalent chromium compounds or biocides (note the related entry on list B B3090)
- A3110 Fellmongery wastes containing hexavalent chromium compounds or biocides or infectious substances (note the related entry on list B B3110)
- A3120 Fluff – light fraction from shredding
- A3150 Waste halogenated organic solvents
- A3160 Waste halogenated or unhalogenated non-aqueous distillation residues arising from organic solvent recovery operations
- A4010 Wastes from the production, preparation and use of pharmaceutical products but excluding such wastes specified on list B
- A4020 Clinical and related wastes; that is wastes arising from medical, nursing, dental, veterinary, or similar practices, and wastes generated in hospitals or other facilities during the investigation or treatment of patients, or research projects
- A4040 Wastes from the manufacture formulation and use of wood preserving chemicals⁷
- A4070 Wastes from the production, formulation and use of inks, dyes, pigments, paints, lacquers, varnish excluding any such waste specified on list B (note the related entry on list B B4010)
- A4100 Wastes from industrial pollution control devices for cleaning of industrial off-gases but excluding such wastes specified on list B
- A4130 Waste packages and containers containing Annex I substances in concentrations sufficient to exhibit Annex III hazard characteristics
- A4140 Wastes consisting of or containing off specification or outdated⁸ chemicals corresponding to Annex I categories and exhibiting Annex III hazard characteristics

⁷ This entry does not include wood treated with wood-preserving chemicals.

⁸ “Outdated” means unused within the period recommended by the manufacturer.

A4150 Waste chemical substances arising from research and development or teaching activities which are not identified and/or are new and whose effects on human health and/or the environment are not known

A4160 Spent activated carbon not included on list B (note the related entry on list B B2060)

21. As stated in Article 1, paragraph 1 (b), “Wastes that are not covered under paragraph (a) but are defined as, or are considered to be, hazardous wastes by the domestic legislation of the Party of export, import or transit” are also subject to the Basel Convention.

B. Stockholm Convention

1. General provisions

22. The objective of the Stockholm Convention, which entered into force on 17 May 2004, is set forth in article 1 (“Objective”): “Mindful of the precautionary approach as set forth in Principle 15 of the Rio Declaration on Environment and Development, the objective of this Convention is to protect human health and the environment from persistent organic pollutants”.

23. The Stockholm Convention differentiates between two categories of POPs:

(a) Intentionally produced POPs, whose production and use are to be:

- (i) Eliminated in accordance with the provisions of article 3 and Annex A; or
- (ii) Restricted in accordance with the provisions of article 3 and Annex B;

(b) Unintentionally produced POPs, for which Parties are required to take measures, in accordance with article 5 and Annex C, to reduce total releases derived from anthropogenic sources, with the goal of their continuing minimization and, where feasible, ultimate elimination.

24. Under article 7 (“Implementation plans”), paragraph 1, the Convention requires each Party to:

“(a) Develop and endeavour to implement a plan for the implementation of its obligations under the Convention;

(b) Transmit its implementation plan to the Conference of the Parties within two years of the date on which this Convention enters into force for it; and

(c) Review and update, as appropriate, its implementation plan on a periodic basis and in a manner to be specified by a decision of the Conference of the Parties.”

2. Waste-related provisions

25. Article 6 (“Measures to reduce or eliminate releases from stockpiles and wastes”) sets forth waste related provisions as follows:

“1. In order to ensure that stockpiles consisting of or containing chemicals listed either in Annex A or Annex B and wastes, including products and articles upon becoming wastes, consisting of, containing or contaminated with a chemical listed in Annex A, B or C, are managed in a manner protective of human health and the environment, each Party shall:

(a) Develop appropriate strategies for identifying:

- (i) Stockpiles consisting of or containing chemicals listed either in Annex A or Annex B; and
- (ii) Products and articles in use and wastes consisting of, containing or contaminated with a chemical listed in Annex A, B or C;

(b) Identify, to the extent practicable, stockpiles consisting of or containing chemicals listed either in Annex A or Annex B on the basis of the strategies referred to in subparagraph (a);

(c) Manage stockpiles, as appropriate, in a safe, efficient and environmentally sound manner. Stockpiles of chemicals listed either in Annex A or Annex B, after they are no longer allowed to be used according to any specific exemption specified in Annex A or any specific exemption or acceptable purpose specified in Annex B, except stockpiles which are allowed to be exported according to

paragraph 2 of Article 3, shall be deemed to be waste and shall be managed in accordance with subparagraph (d);

- (d) Take appropriate measures so that such wastes, including products and articles upon becoming wastes, are:
 - (i) Handled, collected, transported and stored in an environmentally sound manner;
 - (ii) Disposed of in such a way that the persistent organic pollutant content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of persistent organic pollutants or otherwise 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, taking into account international rules, standards, and guidelines, including those that may be developed pursuant to paragraph 2, and relevant global and regional regimes governing the management of hazardous wastes;
 - (iii) Not permitted to be subjected to disposal operations that may lead to recovery, recycling, reclamation, direct reuse or alternative uses of persistent organic pollutants; and
 - (iv) Not transported across international boundaries without taking into account relevant international rules, standards and guidelines;
- (e) Endeavour to develop appropriate strategies for identifying sites contaminated by chemicals listed in Annex A, B or C; if remediation of those sites is undertaken it shall be performed in an environmentally sound manner.

2. The Conference of the Parties shall cooperate closely with the appropriate bodies of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal to, inter alia:

- (a) 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;
- (b) Determine what they consider to be the methods that constitute environmentally sound disposal referred to above; and
- (c) 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)."

26. Article 3, paragraph 2 (a) (i), pertaining to imports, stipulates: "Each Party shall take measures to ensure that a chemical listed in Annex A or Annex B is imported only for the purpose of environmentally sound disposal as set forth in paragraph 1 (d) of Article 6." Similarly, article 3, paragraph 2 (b) (i), requires that: "Each Party take measures to ensure that a chemical listed in Annex A for which any production or use specific exemption is in effect or a chemical listed in Annex B for which any production or use specific exemption or acceptable purpose is in effect, taking into account any relevant provisions in existing international prior informed consent instruments, is exported only for the purpose of environmentally sound disposal as set forth in paragraph 1 (d) of Article 6."

27. Annex C, Part II, outlines industrial source categories that have the potential for comparatively high formation and release to the environment of POPs listed in Annex C. Part III outlines source categories from which POPs listed in Annex C may be unintentionally formed and released. Part V outlines general guidance on BAT and BEP.

III. Issues under the Stockholm Convention to be addressed cooperatively with the Basel Convention

A. Low POP content

28. As stated in article 6, paragraph 2 (c), of the Stockholm Convention, the Stockholm Conference of the Parties shall cooperate closely with the appropriate bodies of the Basel Convention to "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)." Wastes consisting of, containing or contaminated with POPs above the low POP content should, in accordance

with article 6, paragraph 1 (d) (ii), be disposed of in such a way that the POP content is destroyed or irreversibly transformed or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option.

29. Recognizing the following considerations:

- (a) Disposal of wastes with a high POP content, including waste stockpiles, should be a priority;
- (b) Availability of treatment capacity;
- (c) Limit values within national legislation are relevant;
- (d) Availability of analytical methods; and
- (e) Lack of knowledge and data;

the following provisional definitions for low POP content should be applied:

- (a) PCBs: 50 mg/kg;⁹
- (b) PCDDs and PCDFs: 15 µg TEQ/kg;¹⁰
- (c) Aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, HCB, mirex and toxaphene: 50 mg/kg for each.¹¹

B. Levels of destruction and irreversible transformation

30. Recognizing the following considerations:

(a) Both destruction efficiency¹² (DE) and destruction removal efficiency¹³ (DRE) are a function of the initial POP content and do not cover formation of unintentionally produced POPs during destruction or irreversible transformation;

(b) DE is an important criterion for helping to assess technologies for destruction and irreversible transformation, but can be difficult to measure in a reproducible and comparable manner, especially on a regular basis;

(c) DRE considers only emissions to air;

(d) BAT and BEP set safe design and operating conditions, including expected destruction efficiencies, in particular circumstances on a technology by technology basis;

(e) BAT and BEP have not been identified for all disposal methods;

(f) Existence of pertinent national legislation and international rules, standards and guidelines;

(g) Lack of knowledge and data;

The following provisional definition for levels of destruction and irreversible transformation, based upon absolute levels (i.e., waste output streams of treatment processes) should be applied:

(a) Atmospheric emissions:

PCDDs and PCDFs: 0.1 ng TEQ/Nm³;¹⁴

All other POPs: pertinent national legislation and international rules, standards and guidelines, examples of pertinent national legislation can be found in annex II;

⁹ Determined according to national or international methods and standards.

¹⁰ TEQ as referred to in annex C, part IV, paragraph 2, of the Stockholm Convention, but only for PCDDs and PCDFs.

¹¹ Determined according to national or international methods and standards

¹² Calculated on the basis of the mass of the POP content within the waste, minus the mass of the remaining POP content in the gaseous, liquid and solid residues, divided by the mass of the POP content within the waste, i.e., $DE = (\text{POP content within waste} - \text{POP content within gas, liquid and solid residual}) / \text{POP content within the waste}$.

¹³ Calculated on the basis of mass of the POP content within the waste, minus the mass of the remaining POP content in the gaseous residues (stack emissions), divided by the mass of the POP content within the wastes, i.e., $DRE = (\text{POP content within waste} - \text{POP content within gas residual}) / \text{POP content within the waste}$.

¹⁴ TEQ as referred to in annex C, Part IV, paragraph 2 of the Stockholm Convention, but only for PCDDs and PCDFs. Nm³ refers to dry gas, 101.3 kPa and 273.15 K. Standardization at 11 per cent O₂.

(b) Aqueous releases: pertinent national legislation and international rules, standards and guidelines, examples of pertinent national legislation can be found in annex II;

(c) Solid residues: POP contents should be below the low POP contents defined in section A above of this chapter. However, if the POP content of unintentionally produced PCDD/PCDFs is above the low POP content defined in section A, the solid residues should be treated in accordance with section IV.G.

In addition, technologies for destruction and irreversible transformation should be operated in accordance with BAT and BEP.

C. Methods that constitute environmentally sound disposal

31. Section G of chapter IV below contains a description of methods that are considered to constitute environmentally sound disposal of wastes consisting of, containing or contaminated with POPs.

IV. Guidance on environmentally sound management (ESM)

A. General considerations

32. ESM is a broad policy concept without a clear universal definition at the current time. However, provisions pertaining to ESM as it applies to wastes consisting of, containing or contaminated with POPs (and, more broadly, to hazardous wastes) within the Basel and Stockholm conventions, and also the Organisation for Economic Co-operation and Development (OECD) core performance elements (discussed in the next three subsections), provide international direction that is also supportive of ESM efforts under way in various countries and among industrial sectors.

1. Basel Convention

33. In its Article 2, paragraph 8, the Basel Convention defines ESM of hazardous wastes or other wastes 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”.

34. In Article 4, paragraph 2 (b), the Convention requires each Party to take the appropriate measures to “ensure the availability of adequate disposal facilities for the environmentally sound management of hazardous or other wastes, that shall be located, to the extent possible, within it, whatever the place of their disposal”, while in paragraph 2 (c) it requires each Party to “ensure that persons involved in the management of hazardous wastes or other wastes within it take such steps as are necessary to prevent pollution due to hazardous wastes and other wastes arising from such management and, if such pollution occurs, to minimize the consequences thereof for human health and the environment”.

35. In Article 4, paragraph 8, the Convention requires that “hazardous wastes or other wastes, to be exported, are managed in an environmentally sound manner in the State of import or elsewhere. Technical guidelines for the environmentally sound management of wastes subject to this Convention shall be decided by the Parties at their first meeting”. The present technical guidelines and the specific technical guidelines are intended to provide a more precise definition of ESM in the context of wastes consisting of, containing or contaminated with POPs, including appropriate treatment and disposal methods for these waste streams.

36. Several key principles with respect to ESM of waste were articulated in the 1994 Framework Document on Preparation of Technical Guidelines for the Environmentally Sound Management of Wastes Subject to the Basel Convention.¹⁵

37. To achieve ESM of wastes, the Framework Document recommends that a number of legal, institutional and technical conditions (ESM criteria) be met, in particular that:

(a) A regulatory and enforcement infrastructure ensures compliance with applicable regulations;

(b) Sites or facilities are authorized and of an adequate standard of technology and pollution control to deal with hazardous wastes in the way proposed, in particular taking into account the level of technology and pollution control in the exporting country;

¹⁵ See Basel Convention 1994 in annex V, Bibliography.

(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 gives indications that the management of hazardous wastes has resulted in unacceptable releases; and

(e) People involved in the management of hazardous wastes are capable and adequately trained in their capacity.

38. ESM is also the subject of the 1999 Basel Declaration on Environmentally Sound Management, adopted at the fifth meeting of the Conference of Parties to the Basel Convention. The Declaration calls on the Parties to enhance and strengthen their efforts and cooperation to achieve ESM, including through prevention, minimization, recycling, recovery and disposal of hazardous and other wastes subject to the Basel Convention, taking into account social, technological and economic concerns; and through further reduction of transboundary movements of hazardous and other wastes subject to the Basel Convention.

39. The Declaration states that a number of activities should be carried out in this context, including:

(a) Identification and quantification of the types of waste being produced nationally;

(b) Best practice approach to avoid or minimize the generation of hazardous wastes and reduce their toxicity, such as the use of cleaner production methods or approaches; and

(c) Provision of sites or facilities authorized as environmentally sound to manage wastes and, in particular, hazardous wastes.

2. Stockholm Convention

40. The term “environmentally sound management” is not defined in the Stockholm Convention. Environmentally sound methods for disposal of wastes consisting of, containing or contaminated with POPs are, however, to be determined by the Conference of Parties in cooperation with the appropriate bodies of the Basel Convention.¹⁶

3. Organisation for Economic Co-operation and Development

41. OECD has adopted a recommendation on ESM of wastes which includes various items, inter alia core performance elements of ESM guidelines applying to waste recovery facilities, including elements of performance that precede collection, transport, treatment and storage and also elements subsequent to storage, transport, treatment and disposal of pertinent residues.¹⁷

42. The core performance elements are:

(a) That the facility should have an applicable environmental management system (EMS) in place;

(b) That the facility should take sufficient measures to safeguard occupational and environmental health and safety;

(c) That the facility should have an adequate monitoring, recording and reporting programme;

(d) That the facility should have an appropriate and adequate training programme for its personnel;

(e) That the facility should have an adequate emergency plan; and

(f) That the facility should have an adequate plan for closure and after-care.

B. Legislative and regulatory framework

43. Parties to the Basel and Stockholm conventions should examine national controls, standards and procedures to ensure that they are in agreement with the conventions and with their obligations under them, including those which pertain to ESM of wastes consisting of, containing or contaminated with POPs.

¹⁶ Parties should consult United Nations Environment Programme (UNEP) 2003 in annex V, Bibliography.

¹⁷ See OECD 2004 in annex V, Bibliography.

44. Most countries already have in place some form of legislation that outlines broad environmental protection principles, powers and rights. Ideally, countries' environmental legislation should include requirements for protection of both human health and the environment. Such enabling legislation can give governments the power to enact specific rules and regulations, inspect and enforce, and establish penalties for violations.

45. Such legislation on hazardous wastes should also define hazardous wastes. Wastes consisting of, containing or contaminated with POPs above the low POP contents referred to in section III.A should be included in the definition. The legislation could define ESM and require adherence to ESM principles, ensuring that countries satisfy provisions for ESM of wastes consisting of, containing or contaminated with POPs, including their environmentally sound disposal as described in the present guidelines and the Stockholm Convention. Specific components or features of a regulatory framework that would meet the requirements of the Basel and Stockholm conventions and other international agreements are discussed below.¹⁸

1. Phase-out dates for production and use of POPs

46. A link should be established in legislation between the phase-out date for production and use¹⁹ of a POP substance (including in products and articles) and the disposal of the POP once it has become a waste. This should include a time limit for disposal of the waste consisting of, containing or contaminated with POPs, so as to prevent massive stockpiles from being created that have no clear phase-out date.

2. Transboundary movement requirements²⁰

47. Hazardous wastes and other wastes should, as far as is compatible with their ESM, be disposed of in the country where they were generated. Transboundary movements of such wastes are permitted only under the following conditions:

- (a) If conducted under conditions that do not endanger human health and the environment;
- (b) If exports are managed in an environmentally sound manner in the country of import or elsewhere;
- (c) If the country of export does not have the technical capacity and the necessary facilities to dispose of the wastes in question in an environmentally sound and efficient manner;
- (d) If the wastes in question are required as a raw material for recycling or recovery industries in the country of import; or
- (e) If the transboundary movements in question are in accordance with other criteria decided by the Parties.

48. Any transboundary movements of hazardous and other wastes are subject to prior written notification from the exporting country and prior written consent from the importing and, if appropriate, transit countries. Parties shall prohibit the export of hazardous wastes and other wastes if the country of import prohibits the import of such wastes. The Basel Convention also requires that information regarding any proposed transboundary movement is provided using the accepted notification form and that the approved consignment is accompanied by a movement document from the point where the transboundary movement commences to the point of disposal.

49. Furthermore, hazardous wastes and other wastes subject to transboundary movements should be packaged, labelled and transported in conformity with international rules and standards.²¹

50. When transboundary movement of hazardous and other wastes to which consent of the countries concerned has been given cannot be completed, the country of export shall ensure that the wastes in question are taken back into the country of export for their disposal if alternative arrangements cannot

¹⁸ Further guidance on Basel Convention regulatory frameworks can be found in the following documents: Model National Legislation on the Management of Hazardous Wastes and Other Wastes as well as on the Control of Transboundary Movements of Hazardous Wastes and Other Wastes and their Disposal (UNEP, 1995a), Basel Convention: Manual for Implementation (UNEP, 1995b) and Basel Convention: Guide to the Control System (UNEP, 1998a). Parties to the Stockholm Convention should also consult *Guidance for developing a NIP for the Stockholm Convention* (UNEP, 2005). See annex V, Bibliography.

¹⁹ Note that annex A, parts I and II, and annex B of the Stockholm Convention give references to the elimination and restriction of production and use of POPs.

²⁰ This applies only to Basel Convention Parties.

²¹ In this connection, the United Nations Recommendations on the Transport of Dangerous Goods (Model Regulations) (UNECE, 2003a – see annex V, Bibliography) or later versions should be used.

be made. In the case of illegal traffic (as defined in Article 9, paragraph 1), the country of export shall ensure that the wastes in question are taken back into the country of export for their disposal or disposed of in accordance with the provisions of the Basel Convention.

51. No transboundary movements of hazardous wastes and other wastes are permitted between a Party and a non-Party to the Basel Convention unless a bilateral, multilateral or regional arrangement exists as required under Article 11 of the Basel Convention.

3. Specifications for containers, equipment, bulk containers and storage sites containing POPs

52. To meet the requirements of ESM and specific clauses in the Basel and Stockholm conventions (for example, Basel Convention Article 4, paragraph 7, and Stockholm Convention article 6, paragraph 1), Parties may need to enact specific legislation that describes the types of containers and storage areas that are acceptable for particular POPs.²² Parties should ensure that containers that may be transported to another country meet international standards such as those established by the International Air Transport Association (IATA), the International Maritime Organization (IMO) and the International Organization for Standardization (ISO).

4. Health and safety²³

53. Neither the Basel nor the Stockholm convention specifically requires Parties to have worker health and safety legislation. A legislative approach should be taken, however, to protect workers from possible exposure to POPs. These provisions should include requirements for the proper labelling of products and the identification of appropriate disposal methods.

54. Most countries have existing worker health and safety provisions either in general labour legislation or in specialized human health or environmental legislation. Parties should re-examine their existing legislation to ensure that POPs are adequately addressed and that relevant aspects of international agreements are integrated. Worker health and safety is a relatively mature field and a great deal of guidance and literature is available to assist in the planning and revision of legislation, policy and technical guidance.

55. In its article 10 (“Public information, awareness and education”), paragraph 1 (e), the Stockholm Convention calls upon Parties to promote and facilitate training for workers, scientists, educators and technical and managerial personnel. National health and safety legislation should include provisions for the safe handling and storage of wastes consisting of, containing or contaminated with POPs.

5. Specification of acceptable analytical and sampling methods for POPs

56. Many different sampling and analytical methods have been developed for a variety of purposes. Reliable and useful data can be generated only when sampling and analytical methods appropriate to the waste are used. All Parties to the Basel and Stockholm conventions should have legislation or strong policy guidelines identifying the acceptable sampling and analytical methods for each POP waste, including the form in which it occurs and the matrix. The procedures specified should be accepted internationally. This should ensure that the reported results are comparable. See section E of this chapter for further detail.

6. Requirements for hazardous waste treatment and disposal facilities

57. Most countries have legislation that requires waste treatment and disposal facilities to obtain some form of approval to commence operations. Approvals can outline specific conditions which must be maintained in order for approval to remain valid. It may be necessary to add requirements specific to wastes consisting of, containing or contaminated with POPs to meet the requirements of ESM and to comply with specific requirements of the Basel and Stockholm conventions.

7. General requirement for public participation

58. Public participation is a core principle of the Basel Declaration on Environmentally Sound Management and many other international agreements. Public participation as referred to in section IV.K below may be addressed in legislation or policy.

²² Parties should consult Food and Agriculture Organization (FAO) guidelines pertaining to the storage of pesticides and pesticide waste (FAO, 1996 – see annex V, Bibliography).

²³ See also section IV.I.

8. Contaminated sites

59. Provisions enabling the development of an inventory of contaminated sites and remediation of sites in an environmentally sound manner (article 6, paragraph 1 (e), of the Stockholm Convention) may be specified in legislation.

9. Other legislative controls

60. Examples of other aspects of life-cycle management of wastes consisting of, containing or contaminated with POPs that could be required through legislation include:

- (a) Siting provisions and requirements relative to the storage, handling, collection and transport of wastes;
- (b) Decommissioning requirements including:
 - (i) Inspection prior to and during decommissioning;
 - (ii) Procedures to be followed to protect worker and community health and the environment during decommissioning;
 - (iii) Post-decommissioning site requirements;
- (c) Emergency contingency planning, spill and accident response, including:
 - (i) Cleanup procedures and post-cleanup concentrations to be achieved;
 - (ii) Worker training and safety requirements;
- (d) Waste prevention, minimization and management plans.

C. Waste prevention and minimization

61. The prevention and minimization of wastes consisting of, containing or contaminated with POPs are the first and most important steps in the overall ESM of such wastes. In its Article 4, paragraph 2, the Basel Convention calls on Parties to “ensure that the generation of hazardous wastes and other wastes ... is reduced to a minimum”.

62. Elements of a waste prevention and minimization programme include the following:

- (a) Identification of processes unintentionally producing POPs and determination of whether Stockholm Convention guidelines on BAT and BEP are applicable;
- (b) Identification of processes that use POPs and generate wastes consisting of, containing or contaminated with POPs:
 - (i) To determine whether process modifications, including updating older equipment, could reduce waste generation;
 - (ii) To identify alternative processes that are not linked to the production of wastes consisting of, containing or contaminated with POPs;
- (c) Identification of products and articles consisting of, containing or contaminated with POPs and non-POP alternatives;
- (d) Minimization of the volume of waste generated:
 - (i) By regular maintenance of equipment to increase efficiency and prevent spills and leaks;
 - (ii) By prompt containment of spills and leaks;
 - (iii) By decontamination of containers and equipment containing wastes consisting of, containing or contaminated with POPs;
 - (iv) By isolation of wastes consisting of, containing or contaminated with POPs in order to prevent contamination of other materials.

63. Generators of wastes and significant downstream industrial users (e.g., pesticide formulators) of products and articles containing POPs could be required to develop waste management plans. Such plans should cover all hazardous wastes, with wastes consisting of, containing or contaminated with POPs wastes treated as one component.

64. Mixing of wastes with POP contents above a defined low POP content with other materials solely for the purpose of generating a mixture with a POP content below the defined low POP content is

not environmentally sound. Nevertheless, mixing of materials prior to waste treatment may be necessary in order to optimize treatment efficiencies.

D. Identification and inventories

1. Identification

65. In paragraph 1 of article 6, the Stockholm Convention requires:

(a) Identification of stockpiles consisting of or containing chemicals listed in Annex A or Annex B; and

(b) Development of appropriate strategies for the identification of products and articles in use and wastes consisting of, containing or contaminated with POPs.

66. Wastes consisting of, containing or contaminated with POPs occur as solids and liquids (aqueous, semi-aqueous, solvent-based and emulsions) and can be released as gases (actual gases, as a liquid dispersion or aerosols, or adsorbed onto atmospheric pollutants).

67. Wastes consisting of, containing or contaminated with POPs are mostly generated as a result of human activities, for example:

(a) During their intentional manufacture;

(b) As by-products of industrial and other processes;

(c) Through contamination of materials or the environment as a result of accidents or leakage that may occur during production, sales, use, decommissioning, removal or transfer;

(d) Through contamination of materials during handling and use of products and articles such as containers, clothing and in some cases equipment (respirators, etc.) that have been contaminated through contact with a pesticide product;

(e) When products or articles contaminated with POPs become off-specification, are unfit for the original use or are discarded;

(f) When products have been banned or when registrations for such products have been withdrawn.

68. Critical aspects of waste identification require knowledge of products or articles consisting of, containing or contaminated with POPs, including manufacturers, trade names and synonyms, when they were manufactured, how they were used and who used them. The list of source categories provided in annex C to the Stockholm Convention should assist industrial managers and government regulators, and also the general public, in identifying wastes consisting of, containing or contaminated with unintentionally produced POPs.

2. Inventories

69. National implementation plans under the Stockholm Convention will include a national inventory. For the purpose of the environmentally sound management of wastes, a more specific and complete inventory may be needed. This will normally involve an iterative process. The following paragraphs provide more detailed guidance.

70. Inventories are an important tool for identifying, quantifying and characterizing wastes. National inventories may be used:

(a) To establish a baseline quantity of products, articles and wastes consisting of, containing or contaminated with POPs;

(b) To establish an information registry to assist with safety and regulatory inspections;

(c) To obtain the accurate information needed to draw up plans for site stabilization;

(d) To assist with the preparation of emergency response plans;

(e) To track progress towards minimizing and phasing out POPs.

71. When developing an inventory, priority should be given to the identification of wastes with high POP concentrations.

72. An inventory should, as appropriate, include data on:

(a) Production of POPs within the country;

(b) Import/export of products and articles consisting of or containing POPs;

- (c) Disposal of waste consisting of, containing or contaminated with POPs;
- (d) Import/export of such waste.

73. The development of a national POPs inventory requires cooperation by the relevant authority with producers, users, transporters, customs offices, waste disposal facilities and the national focal points for the Basel Convention and for the Stockholm Convention. It requires also a long-term commitment by the national government, cooperation from owners and manufacturers of POPs, a sound administrative process for collecting information on an ongoing basis and a computerized database system for storage of information. In some cases, government regulations may be required to ensure that owners report their holdings and cooperate with government inspectors.

74. The first issue to consider in developing an inventory is the types of industries and locations which may have been using POPs. This should help provide a sense of the magnitude of the inventory effort and can help to develop a preliminary list of possible owners. If POPs have been produced in or imported into the country, the industries involved should also be part of the initial consultations. These companies may be able to give estimates or even exact figures of the amount of these products that were used in domestic applications. These estimates can be very valuable in determining how much of a chemical has been accounted for by an inventory. Unfortunately, in some cases these records may no longer exist.

75. There are five basic steps in the development of an inventory, as set forth below.

Step 1: Consult with key industries and associations: Government officials should meet with representatives of industries that are likely to own large quantities of products, articles or wastes consisting of, containing or contaminated with POPs, and with former producers and distributors. Since chemical, agricultural, electrical, and other large industries probably own or have knowledge about a large percentage of the country's total amount of POPs, they should be consulted first. Government officials should also meet with non-governmental organizations to seek their assistance.

Step 2: Train personnel: Government staff members who are responsible for the inventory should be trained in all aspects of products, articles and wastes. The key training elements should include the identification of products, articles and wastes consisting of, containing or contaminated with POPs; audits and inspections; health and safety; and procedures for setting up and maintaining inventories.

Step 3: Conduct several trial audits: Several facilities should be visited by government personnel. These visits should serve three purposes. First, they will familiarize government staff with the inventory process and actual on-site conditions. Second, they will serve as another form of consultation with industry. Third, they will produce some inventory information that can be used as trial data for the development of the national inventory.

Step 4: Develop policy or regulations requiring owners to report POPs: A draft policy or regulation regarding the tracking of POPs and reporting to the Government for inventory purposes should be developed. The policy or regulation should require initial reporting by a certain date and subsequent reporting when changes to inventories are made by owners or when disposal occurs. The reporting requirement should request specific information for each distinct inventory item, including:

- (a) Name or description of product, article or waste;
- (b) Physical state (liquid, solid, sludge, gas);
- (c) Weight of container or equipment (if applicable);
- (d) Weight of material consisting of, containing or contaminated with POPs;
- (e) Number of similar containers or pieces of equipment;
- (f) Concentration of POPs in the product, article or waste;
- (g) Other hazards associated with the material (e.g., combustible, corrosive, flammable);
- (h) Location;
- (i) Owner information;
- (j) Identifying labels, serial numbers, marks, etc.;
- (k) Date entered inventory;
- (l) Date removed from inventory and fate (if applicable).

Step 5: Implement the plan: Before implementing the requirement to report inventories, a national inventory database should be set up. The Government's central inventory should be kept up to date as new information comes in. Governments can assist owners by providing information and advice. Site inspections should help ensure that the inventory information is correct.²⁴

76. In addition, it should be noted that the 2003 Protocol on Pollutant Release and Transfer Register to the 1998 United Nations Economic Commission for Europe (UNECE) Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters includes provisions pertaining to the inventories that may be applicable to POPs.

E. Sampling, analysis and monitoring

77. Sampling, analysis and monitoring are critical components in the management of wastes consisting of, containing or contaminated with POPs and should be given high priority with respect to both capacity-building in developing countries and implementation. Sampling, analysis and monitoring should be conducted by trained professionals in accordance with a well-designed plan and using internationally accepted or nationally approved methods, carried out using the same method each time over the time span of the programme. They should also be subjected to rigorous quality assurance and quality control measures. Mistakes in sampling, analysis or monitoring, or deviation from standard operational procedures, can result in meaningless data or even programme-damaging data. Each Party, as appropriate, should therefore ensure that training, protocols and laboratory capability are in place for sampling, monitoring and analytical methods and that these standards are enforced.

78. Because there are numerous reasons to sample, analyse and monitor, and also because there are so many different physical forms of waste, there are hundreds of different methods that can be used for sampling, analysis and monitoring. It is beyond the scope of this document to discuss even a few of the actual methods. In the next three sections, however, the key points of sampling, analysis and monitoring are considered.

79. For information on good laboratory practices the OECD series (OECD, various years) may be consulted; on general methodological considerations, the guidance document for the Global Monitoring Programme on POPs (UNEP 2004a) may be used; and further information on POPs analysis may be obtained from the UNEP/Global Environment Facility (GEF) project on capacity needs for analysing POPs at www.chem.unep.ch/pops/laboratory/default.htm.

1. Sampling²⁵

80. The overall objective of any sampling activity is to obtain a sample which can be used for the targeted purpose, e.g., site characterization, compliance with regulatory standards or suitability for proposed treatment or disposal. This objective should be identified before sampling is started. It is indispensable for quality requirements in terms of equipment, transportation and traceability to be met.

81. Standard sampling procedures should be established and agreed upon before the start of the sampling campaign (both matrix- and POP-specific). Elements of these procedures include the following:

- (a) The number of samples to be taken, the sampling frequency, the duration of the sampling project and a description of the sampling method (including quality assurance procedures put in place, e.g., field blanks and chain-of-custody);
- (b) Selection of location or sites and time of sample-taking (including description and geographic localization);
- (c) Identity of person who took the sample and conditions during sampling;
- (d) Full description of sample characteristics – labelling;
- (e) Preservation of the integrity of samples during transport and storage (before analysis);
- (f) Close cooperation between the sampler and the analytical laboratory;
- (g) Appropriately trained sampling personnel.

²⁴ Further information on inventories can be found in the Methodological Guide for the Undertaking of National Inventories of Hazardous Wastes Within the Framework of the Basel Convention (see UNEP 2000a in annex V, Bibliography).

²⁵ Further information on sampling is available in RCRA Waste Sampling Draft Technical Guidance (United States Environmental Protection Agency, 2002, and Nordtest method. See annex V, Bibliography).

82. Sampling should comply with specific national legislation, where it exists, or with international regulations. In countries where regulations do not exist, qualified staff should be appointed. Sampling procedures include the following:

- (a) Development of a standard operational procedure (SOP) for sampling each of the matrices for subsequent POPs analysis;
- (b) Application of well-established sampling procedures such as those developed by the American Society for Testing and Materials (ASTM), the European Union, the United States Environmental Protection Agency (EPA) and the Global Environment Monitoring System (GEMS);
- (c) Establishment of quality assurance and quality control (QA/QC) procedures.

83. All these steps should be followed for a sampling programme to be successful. Similarly, documentation should be thorough and rigorous.

84. Types of matrices typically sampled for POPs include solids, liquid and gases:

- (a) Liquids:
 - (i) Leachate from dumpsites and landfills;
 - (ii) Liquid collected from spills;
 - (iii) Water (surface water, drinking water and industrial effluents);
 - (iv) Biological fluids (blood, in the case of workers' health monitoring);
- (b) Solids:
 - (i) Stockpiles, products and formulations consisting of, containing or contaminated with POPs;
 - (ii) Solids from industrial sources and treatment or disposal processes (fly ash, bottom ash, sludge, still bottoms, other residues, clothing, etc.);
 - (iii) Containers, equipment or other packaging materials (rinse or wipe samples), including the tissues or fabric used in the collection of wipe samples;
 - (iii) Soil, sediment, rubble, sewage sludge and compost;
- (c) Gases:
 - (i) Air (indoor).

85. In environmental and human monitoring programmes, both biotic and abiotic matrices may be included:

- (a) Plant materials and food;
- (b) Human breast milk or blood;
- (c) Air (ambient, wet or dry deposition or, possibly, snow).

2. Analysis

86. Analysis refers to the extraction, purification, separation, identification, quantification and reporting of POPs concentrations in the matrix of interest. To obtain meaningful and acceptable results, the analytical laboratory should have the necessary infrastructure (housing) and proven experience with the matrix and the POP (e.g., successful participation in international intercalibration studies). Accreditation of the laboratory according to ISO 17025 or other standards by an independent body is an important aspect. Indispensable criteria for obtaining high-quality results include:

- (a) Specification of the analytical technique;
- (b) Maintenance of analytical equipment;
- (c) Validation of all methods used (including in-house methods);
- (d) Training of laboratory staff.

87. Typically, POPs analysis is performed in a dedicated laboratory. For specific situations, test kits are available that can be used in the field for screening purposes.

88. For laboratory POPs analysis, there is no one analytical method available. Methods of analysing the various matrices for POPs have been developed by ISO, the European Committee for Standardization (CEN), EPA, AOAC and ASTM. Annex III lists some examples. Most in-house methods are variations of these, and after validation such in-house methods are also acceptable.

89. In addition, procedures and acceptance criteria for handling and preparation of the sample in the laboratory, e.g., homogenization, should be established.

90. The individual steps in the analytical determination include:

- (a) Extraction, e.g., by Soxhlet, accelerated solvent extraction (ASE), liquid-liquid, etc.;
- (b) Purification, e.g., by column chromatography or with Florisil. Purification should be efficient enough so that chromatographic retention is not influenced by the matrix;
- (c) Separation by capillary gas chromatography (HRGC), which will provide sufficient separation of analytes;
- (d) Identification by suitable detectors such as an electron capture detector (ECD) or a mass-selective detector (MSD), or by either low-resolution mass spectrometry or high-resolution mass spectrometry (LRMS or HRMS);
- (e) Quantification according to internal standard methodology (for reference, see UNEP 2004a, UNEP, 2006);
- (f) Reporting in accordance with regulation(s).

3. Monitoring

91. In paragraph 2 (b) of its Article 10 (“International Cooperation”), the Basel Convention requires Parties to “cooperate in monitoring the effects of the management of hazardous wastes on human health and the environment”. In paragraph 1 of its article 11, the Stockholm Convention requires Parties to encourage and/or undertake appropriate monitoring pertaining to the POPs. Monitoring programmes should provide an indication of whether a hazardous waste management operation is functioning in accordance with its design, and should detect changes in environmental quality caused by the operation. The information from the monitoring programme should be used to ensure that the proper types of hazardous wastes are being managed by the waste management operation, to discover and repair any damage and to determine whether an alternative management approach might be appropriate. By implementing a monitoring programme, facility managers can identify problems and take appropriate measures to remedy them.²⁶

F. Handling, collection, packaging, labelling, transportation and storage

92. Handling, collection, packaging, labelling, transportation and storage are critically important steps as the risk of a spill, leak or fire (for example, in preparation for storage or disposal) is at least as great as at other times.

93. For transport and transboundary movement of hazardous wastes, the following documents should be consulted to determine specific requirements:

- (a) Basel Convention: Manual for Implementation (UNEP, 1995);
- (b) International Maritime Dangerous Goods Code (IMO, 2002);
- (c) International Civil Aviation Organization (ICAO) Technical Instructions for the Transport of Dangerous Goods;
- (d) IATA Dangerous Goods Regulations and the United Nations Recommendations on the Transport of Dangerous Goods Model Regulations (Orange Book).

94. For the following sections 1–6, detailed information can be obtained from “Destruction and Decontamination Technologies for PCBs and other POPs wastes under the Basel Convention, a Training Manual for Hazardous Waste Project Managers, Volumes A and B” by the Secretariat of the Basel Convention (UNEP, 2002).

95. Wastes consisting of, containing or contaminated with POPs above the low POP contents referred to in section III.A should be managed as hazardous waste, to prevent spills and leaks leading to worker exposure, releases to the environment and exposure to the community.

²⁶ Further information on monitoring is available in Reference Document on the General Principles of Monitoring (European Commission, 2003) and Guidance for a Global Monitoring Programme for Persistent Organic Pollutants (UNEP, 2004a). See annex V “Bibliography”.

1. Handling²⁷

96. The main concerns when handling wastes consisting of, containing or contaminated with POPs are human exposure, accidental release to the environment and contamination of other waste streams with POPs. Such wastes should be handled separately from other waste types in order to prevent contamination of other waste streams. Recommended practices for this purpose include:

- (a) Inspecting containers for leaks, holes, rust or high temperature, and appropriate repackaging and relabelling as necessary;
- (b) Handling wastes at temperatures below 25°C, if possible, because of the increased volatility at higher temperatures;
- (c) Ensuring that spill containment measures are adequate and would contain liquid wastes if spilled;
- (d) Placing plastic sheeting or absorbent mats under containers before opening them if the surface of the containment area is not coated with a smooth surface material (paint, urethane or epoxy);
- (e) Removing liquid wastes either by removing the drain plug or by pumping with a peristaltic pump and suitable chemical-resistant tubing;
- (f) Using dedicated pumps, tubing and drums, not used for any other purpose, to transfer liquid wastes;
- (g) Cleaning up any spills with cloths, paper towels or absorbent;
- (h) Triple rinsing of contaminated surfaces with a solvent such as kerosene;
- (i) Treating all absorbents and solvent from triple rinsing, disposable protective clothing and plastic sheeting as wastes containing or contaminated with POPs when appropriate.

97. Staff should be trained in the correct methods of handling wastes consisting of, containing or contaminated with POPs.

2. Collection

98. Although large industries may be responsible for the proper management of wastes consisting of, containing or contaminated with POPs that they generate or own, many smaller entities also possess such wastes. The wastes consisting of, containing or contaminated with POPs possessed by small entities may include household- or commercial-sized pesticide containers, PCB fluorescent light ballasts, small containers of pentachlorophenol-based wood preservatives with PCDD and PCDF contamination, small amounts of “pure” POPs in laboratories and research facilities, and pesticide-coated seeds used in agricultural and research settings. To deal with this scattered assortment of hazardous wastes, many governments have established depots where small quantities of these wastes can be deposited by the owner at no charge or for a nominal fee. These depots may be permanent or temporary in nature, or may be located at existing commercial hazardous-waste transfer stations. Waste-collection depots and transfer stations may be set up on a regional basis by groups of countries or may be provided by a developed country to a developing country.

99. Care should be taken in establishing and operating waste collection programmes, depots and transfer stations:

- (a) To advertise the programme, depot locations and collection time periods to all potential holders of wastes consisting of, containing or contaminated with POPs;
- (b) To allow enough time of operation of collection programmes for the complete collection of all potential wastes consisting of, containing or contaminated with POPs;²⁸
- (c) To include, to the extent practical, all wastes consisting of, containing or contaminated with POPs in the programme;
- (d) To make acceptable containers and safe-transport materials available to waste owners for those waste materials that may need to be repackaged or made safe for transport;
- (e) To establish simple, low-cost mechanisms for collection;

²⁷ Examples of guidelines on the safe handling of hazardous materials and accident prevention include those prepared by the International Labour Organization (1999a and 1999b) and OECD (2003), listed in annex V, “Bibliography”.

²⁸ Complete collection may require the depots to operate either continuously or intermittently over several years.

- (f) To ensure the safety both of those delivering waste to depots and workers at the depots;
- (g) To ensure that the operators of depots are using an accepted method of disposal;
- (h) To ensure that the programme and facilities meet all applicable legislative requirements;
- (i) To ensure separation of wastes consisting of, containing or contaminated with POPs from other waste streams.

3. Packaging

100. Wastes consisting of, containing or contaminated with POPs should be properly packaged for ease of transport and as a safety measure to reduce the risk of leaks and spills. Packaging of hazardous wastes falls into two categories: packaging for transport and packaging for storage.

101. Packaging for transport is often controlled by national dangerous goods transportation legislation. For packaging specifications for transport, the reader should consult reference material published by IATA, IMO, UNECE and national governments.

102. Some general precepts for packaging of wastes consisting of, containing or contaminated with POPs for storage are as follows:

- (a) Packaging that is acceptable for transport is, in most cases, suitable for storage;
- (b) Such wastes in their original product containers are generally safe for storage if the packaging is in good condition;
- (c) Such wastes should never be stored in product containers that were not intended to contain such wastes or that have labels on them that incorrectly identify the contents;
- (d) Containers that are deteriorating or are deemed to be unsafe should be emptied or placed inside a sound outer package (overpack). When unsafe containers are emptied, the contents should be placed in appropriate new or refurbished containers. All new or refurbished containers should be clearly labelled as to their contents;
- (e) Smaller containers can be packaged together in bulk by placing them in appropriate or approved larger containers containing absorbent material;
- (f) Out-of-service equipment containing POPs may or may not constitute suitable packaging for storage. The determination of safety should be made on a case-by-case basis.

4. Labelling²⁹

103. Labelling of products and articles consisting of, containing or contaminated with POPs is critical for the success of inventories and is a basic safety feature of any waste management system. Each waste container should be labelled to identify the container (e.g., ID number), the POPs present and the hazard level.

5. Transportation

104. Wastes consisting of, containing or contaminated with POPs should be transported in an environmentally sound manner to avoid accidental spills and to track their transport and ultimate destination appropriately. Before transport, contingency plans should be prepared in order to minimize environmental impacts associated with spills, fires and other emergencies that could occur during transport. During transportation, such wastes should be identified, packaged and transported in accordance with the "United Nations Recommendations on the Transport of Dangerous Goods: Model Regulations (Orange Book)". Persons transporting such wastes should be qualified and certified as carriers of hazardous materials and wastes.

105. Transportation of dangerous goods and wastes is regulated in most countries and the transboundary movement of wastes is controlled, in particular by the Basel Convention.

106. Companies transporting wastes within their own countries should be certified as carriers of hazardous materials and wastes, and their personnel should be qualified.

107. Guidance on the safe transportation of hazardous materials can be obtained from IATA, IMO, UNECE and ICAO.

²⁹ International standards have been developed for the proper labelling and identification of wastes. Guidelines on the proper labelling and identification of hazardous materials have been produced by UNECE (2003b) and OECD (2001). See also "Training manual on inventory taking of obsolete pesticides", Series No 10 and reference No X9899 (FAO, 2001) and UNEP (1995b) in annex V, Bibliography.

6. Storage³⁰

108. Wastes consisting of, containing or contaminated with POPs should be stored safely, preferably in dedicated areas away from other materials and wastes. Storage areas should be designed to prevent the release of POPs to the environment by any route. Storage rooms, areas or buildings should be designed by professionals with expertise in the fields of structural design, waste management and occupational health and safety or can be purchased in prefabricated form from reputable suppliers.

109. Some basic principles of safe storage of wastes consisting of, containing or contaminated with POPs are as follows:

- (a) Storage sites inside multi-purpose buildings should be in a locked dedicated room or partition that is not in an area of high use;
- (b) Outdoor dedicated storage buildings or containers³¹ should be stored inside a lockable fenced enclosure;
- (c) Separate storage areas, rooms or buildings should be used for each type of POPs waste, unless specific approval has been given for joint storage;
- (d) Such wastes should not be stored at or near sensitive sites such as hospitals or other medical care facilities, schools, residences, food processing facilities, animal feed storage or processing facilities, agricultural operations, or facilities located near or within environmentally sensitive sites;
- (e) Storage rooms, buildings and containers should be located and maintained in conditions that will minimize volatilization, including cool temperatures, reflective roofs and sidings, a shaded location, etc. When possible, particularly in warmer climates, storage rooms and buildings should be maintained under negative pressure with exhaust gases vented through carbon filters, bearing in mind the following conditions:
 - (i) Ventilating a site with carbon filtration of exhaust gases may be appropriate when exposure to vapours for those who work at the site and those living and working in the vicinity of the site is a concern;
 - (ii) Sealing and venting a site so that only well-filtered exhaust gases are released to outside air may be appropriate when environmental concerns are paramount;
- (f) Dedicated buildings or containers should be in good condition and made of hard plastic or metal, not wood, fibreboard, drywall, plaster or insulation;
- (g) The roofs of dedicated buildings or containers and the surrounding land should be sloped to provide drainage away from the site;
- (h) Dedicated buildings or containers should be set on asphalt, concrete or durable (e.g., 6 mm) plastic sheeting;
- (i) The floors of storage sites inside buildings should be concrete or durable (e.g., 6 mm plastic sheeting). Concrete should be coated with a durable epoxy polymer;
- (j) Storage sites should have fire alarm systems;
- (k) Storage sites inside buildings should have (preferably non-water) fire suppression systems. If the fire suppressant is water, then the floor of the storage room should be curbed and the floor drainage system should not lead to the sewer or storm sewer or directly to surface water but should have its own collection system, such as a sump;
- (l) Liquid wastes should be placed in containment trays or a curbed, leak-proof area. The liquid containment volume should be at least 125 per cent of the liquid waste volume, taking into account the space taken up by stored items in the containment area;
- (m) Contaminated solids should be stored in sealed containers such as barrels or pails, steel waste containers (lugger boxes) or in specially constructed trays or containers. Large volumes of material may be stored in bulk in dedicated shipping containers, buildings or vaults so long as they meet the safety and security requirements as described herein;
- (n) A complete inventory of such wastes in the storage site should be created and kept up to date as waste is added or disposed of;

³⁰ Further information can be found in *Storage of Hazardous Materials: A Technical Guide for Safe Warehousing of Hazardous Materials* (UNEP, 1993 – see annex V, Bibliography). *Pesticide storage and stock control manual, No 3* (FAO, 1996).

³¹ Shipping containers are often used for storage.

(o) The outside of the storage site should be labelled as a waste storage site;

(p) The site should be subjected to routine inspection for leaks, degradation of container materials, vandalism, integrity of fire alarms and fire suppression systems and general status of the site.

G. Environmentally sound disposal

1. Pre-treatment

110. This section presents some of the pre-treatment operations that may be required for the proper and safe operation of the disposal technologies described in the following subsections 2 and 3. There are also other pre-treatment operations which may be applied. Pre-treatment operations prior to disposal according to subsections 2 and 3 should be performed only if the POPs that are isolated from the waste during pre-treatment are subsequently disposed of in accordance with subsection 2. Where only part of a product or waste, such as waste equipment, contains or is contaminated with POPs, it should be separated and then disposed of as specified in subsections 1–4, as appropriate.

(a) Adsorption and absorption

111. “Sorption” is the general term for both absorption and adsorption processes. Sorption is a pre-treatment method that uses solids for removing substances from liquids or gases. Adsorption involves the separation of a substance (liquid, oil, gas) from one phase and its accumulation at the surface of another (activated carbon, zeolite, silica, etc.). Absorption is the process whereby a material transferred from one phase to another interpenetrates the second phase (e.g., contaminant transferred from liquid phase onto activated carbon).

112. Adsorption and absorption processes can be used to concentrate contaminants and separate them from aqueous wastes and from gas streams. The concentrate and the adsorbent or absorbent may require treatment prior to disposal.

(b) Dewatering

113. Dewatering is a pre-treatment process that partially removes water from the wastes to be treated. Dewatering can be employed for disposal technologies that are not suitable for aqueous wastes. For example, water will react explosively with molten salts or sodium. Depending on the nature of the contaminant, the resulting vapours may require condensation or scrubbing, and further treatment.

(c) Mechanical separation

114. Mechanical separation can be used to remove larger-sized debris from the waste stream or for technologies that may not be suitable for both soils and solid wastes.

(d) Mixing

115. Mixing of materials prior to waste treatment may be appropriate in order to optimize treatment efficiencies. However, mixing of wastes with POP contents above a defined low POP content with other materials solely for the purpose of generating a mixture with a POP content below the defined low POP content is not environmentally sound.

(e) Oil-water separation

116. Some treatment technologies are not suitable for aqueous wastes; others are not suitable for oily wastes. Oil-water separation can be employed in these situations to separate the oily phase from the water. Both the water and the oily phase may be contaminated after the separation and both may require treatment.

(f) pH adjustment

117. Some treatment technologies are most effective over a defined pH range and in these situations alkali, acid or CO₂ are often used to control pH levels. Some technologies may also require pH adjustment as a post-treatment step.

(g) Size reduction

118. Some technologies are able to process wastes only within a certain size limit. For example, some may handle POP-contaminated solid wastes only if they are less than 200 mm in diameter. Size reduction can be used in these situations to reduce the waste components to a defined diameter. Other disposal technologies require slurries to be prepared prior to injection into the main reactor. It should be

noted that facilities may become contaminated when reducing the size of wastes consisting of, containing or contaminated with POPs. Precautions should therefore be taken to prevent subsequent contamination of POP-free waste streams.

(h) Solvent washing

119. Solvent washing can be used to remove POPs from electrical equipment such as capacitors and transformers. This technology has also been used for the treatment of contaminated soil and sorption materials used in adsorption or absorption pre-treatment.

(i) Thermal desorption

120. Low-temperature thermal desorption (LTTD), also known as low-temperature thermal volatilization, thermal stripping and soil roasting, is an ex-situ remedial technology that uses heat physically to separate volatile and semi-volatile compounds and elements (most commonly petroleum hydrocarbons) from contaminated media (most commonly excavated soils). Such processes have been used for the decontamination of the non-porous surfaces of electrical equipment such as transformer carcasses that formerly contained PCB-containing dielectric fluids. Thermal desorption of wastes containing or contaminated with POPs may result in the formation of unintentional POPs which may require additional treatment.

2. Destruction and irreversible transformation methods

121. The following disposal operations, as provided for in Annexes IV A and IV B of the Basel Convention, should be permitted for the purpose of destruction and irreversible transformation of the POP content in wastes when applied in such a way as to ensure that the remaining wastes and releases do not exhibit the characteristics of POPs:

- D9 Physico-chemical treatment;
- D10 Incineration on land;
- R1 Use as a fuel (other than in direct incineration) or other means to generate energy;
- R3 Recycling/reclamation of organic substances which are not used as solvents, but restricted to waste-to-gas conversion;
- R4 Recycling/reclamation of metals and metal compounds, but restricted to activities of primary and secondary metallurgy described in (k) below.

122. POPs that are isolated from the waste during pre-treatment should subsequently be disposed of in accordance with operations D9 and D10.

123. This subsection describes commercially available operations for the environmentally sound destruction and irreversible transformation of the POP content in wastes.³² It should be noted that the pertinent national legislation applies for these operations.

124. While the information provided within these guidelines regarding vendors of technologies for destruction and irreversible transformation is believed to be accurate, UNEP disclaims any responsibility for possible inaccuracies or omissions and consequences which may flow from them. Neither UNEP nor any individual involved in the preparation of this report shall be liable for any injury, loss, damage or prejudice of any kind that may be caused by any persons who have acted based on their understanding of the information contained within this publication.

125. Information on the economics of the following technologies can be found in annex IV.

(a) Alkali metal reduction³³

126. *Process description:* Alkali metal reduction involves the treatment of wastes with dispersed alkali metal. Alkali metals react with chlorine in halogenated waste to produce salts and non-halogenated waste. Typically, the process operates at atmospheric pressure and temperatures

³² Further information regarding these technologies or others currently in the pilot or test phase can be found in Review of Emerging, Innovative Technologies for the Destruction and Decontamination of POPs and the Identification of Promising Technologies for Use in Developing Countries (UNEP, 2004b in annex V, Bibliography).

³³ Additional information is available from UNEP, 1998b; UNEP, 2000b; and UNEP, 2004b. See annex V, Bibliography.

between 60°C and 180°C.³⁴ Treatment can take place either in situ (e.g., PCB-contaminated transformers) or ex situ in a reaction vessel. There are several variations of this process.³⁵ Although potassium and potassium-sodium alloy have been used, metallic sodium is the most commonly used reducing agent. The remaining information is based on experiences with the metallic sodium variation.

127. *Efficiency*: Destruction efficiency (DE) values of greater than 99.999 per cent and destruction removal efficiency (DRE) values of 99.9999 per cent have been reported for aldrin, chlordane and PCBs (Ministry of Environment of Japan, 2004). The sodium reduction process has also been demonstrated to meet regulatory criteria in Australia, Canada, Japan, South Africa, the United States of America and the European Union for PCB transformer oil treatment, i.e., less than 2 ppm in solid and liquid residues.³⁶

128. *Waste types*: Sodium reduction has been demonstrated with PCB-contaminated oils containing concentrations up to 10,000 ppm.³⁷ Some vendors have also claimed that this process is capable of treating whole capacitors and transformers.³⁸

129. *Pre-treatment*: Ex-situ treatment of PCBs can be performed, however, following solvent extraction of PCBs. Treatment of whole capacitors and transformers could be carried out following size reduction through shearing.³⁹ Pre-treatment should include dewatering to avoid explosive reactions with metallic sodium.

130. *Emissions and residues*: Air emissions include nitrogen and hydrogen gas. Emissions of organic compounds are expected to be relatively minor.⁴⁰ It has been noted, however, that PCDDs and PCDFs can be formed from chlorophenols under alkaline conditions at temperatures as low as 150°C (Weber, 2004). Residues produced during the process include sodium chloride, sodium hydroxide, polyphenyls and water.⁴¹ In some variations, a solidified polymer is also formed.⁴²

131. *Release control and post-treatment*: After the reaction, the by-products can be separated out from the oil through a combination of filtration and centrifugation. The decontaminated oil can be reused, the sodium chloride can either be reused or disposed of in a landfill and the solidified polymer can be disposed of in a landfill.⁴³

132. *Energy requirements*: Immediate energy requirements are expected to be relatively low owing to the low operating temperatures associated with the sodium reduction process.

133. *Material requirements*: Significant amounts of sodium are required to operate this process.⁴⁴

134. *Portability*: The process is available in transportable and fixed configurations.⁴⁵

135. *Health and safety*: Dispersed metallic sodium can react violently and explosively with water, presenting a major hazard to operators. Metallic sodium can also react with a variety of other substances to produce hydrogen, a flammable gas that is explosive in admixture with air. Great care must be taken in process design and operation absolutely to exclude water (and certain other substances, e.g., alcohols) from the waste and from any other contact with the sodium. In the past, a facility in Delfzijl, the Netherlands, was severely damaged by a fire.

136. *Capacity*: Mobile facilities are capable of treating 15,000 litres per day of transformer oil.⁴⁶

137. *Other practical issues*: Sodium reduction used for in-situ treatment of PCB-contaminated transformer oils may not destroy all the PCBs contained in the porous internals of the transformer. Some authors have noted that there is a lack of information on the characterization of residues.⁴⁷

³⁴ Ariizumi Otsuka, Kamiyama and Hosani, 1997, and Japan Industrial Waste Management Foundation, 1999, see annex V, Bibliography

³⁵ See Piersol, 1989 in annex V, Bibliography.

³⁶ See Piersol, 1989 and UNEP, 2004b in annex V, Bibliography.

³⁷ See UNEP, 2004b in annex V, Bibliography.

³⁸ Ibid.

³⁹ Ibid.

⁴⁰ See Piersol, 1980 in annex V, Bibliography.

⁴¹ See UNEP, 2004b in annex V, Bibliography.

⁴² See UNEP, 2000b, in annex V, Bibliography.

⁴³ Ibid.

⁴⁴ UNEP, 2004b, in annex V, Bibliography.

⁴⁵ Ibid.

⁴⁶ Ibid.

⁴⁷ See UNEP, 2000b, in annex V, Bibliography.

138. *State of commercialization*: This process has been used commercially for approximately 20 years.

139. Vendors include:

- (a) Dr. Bilger Umweltconsulting GmbH – www.bilgergmbh.de;
- (b) Decoman srl, Italy – www.decoman.it;
- (c) Envio Germany GmbH & Co. KG – www.envio-group.com;
- (d) Kinectrics Inc. – www.kinectrics.com;
- (e) Nippon Soda Co. Ltd. – www.nippon-soda.co.jp;
- (f) Orion BV, Netherlands – www.orionun2315.nl/en/index.php.
- (g) Powertech Labs Inc. – www.powertechlabs.com;
- (h) Sanexen Environmental Services Inc. – www.sanexen.com.

(b) Base-catalysed decomposition (BCD)⁴⁸

140. *Process description*: The BCD process involves treatment of wastes in the presence of a reagent mixture consisting of hydrogen-donor oil, alkali metal hydroxide and a proprietary catalyst. When the mixture is heated to above 300°C, the reagent produces highly reactive atomic hydrogen. The atomic hydrogen reacts with the waste to remove constituents that confer the toxicity to compounds.

141. *Efficiency*: DEs of 99.99–99.9999 per cent have been reported for DDT, PCBs, PCDDs and PCDFs.⁴⁹ DEs of greater than 99.999 per cent and DREs of greater than 99.9999 per cent have also been reported for chlordane (Ministry of the Environment of Japan, 2004). It has also been reported that reduction of chlorinated organics to less than 2 mg/kg is achievable.⁵⁰

142. *Waste types*: BCD should be applicable to other POPs in addition to the waste types listed above.⁵¹ BCD should be capable of treating wastes with a high POP concentration, with demonstrated applicability to wastes with a PCB content of above 30 per cent.⁵² It was believed that in practice, the formation of salt within the treated mixture could limit the concentration of halogenated material able to be treated.⁵³ However, the vendor has indicated that the build-up of salt within the reactor simply limits the amount of waste that can be fed to the reactor and that this problem does not appear unsolvable. Applicable waste matrices include soil, sediment, sludge and liquids. The company BCD Group also claims that the process has been shown to destroy PCBs in wood, paper and metal surfaces of transformers.

143. *Pre-treatment*: Soils may be treated directly. Different types of soil pre-treatment may be necessary:

- (a) Larger particles may need to be removed by sifting and crushed to reduce their size; or
- (b) pH and moisture content may need to be adjusted.

144. *Thermal desorption* has also been used in conjunction with BCD to remove POPs from soils prior to treatment. In these situations, the soil is pre-mixed with sodium bicarbonate prior to being fed into the thermal desorption unit.⁵⁴ Water will need to be evaporated from aqueous media, including wet sludge, prior to treatment. Capacitors can be treated following size reduction through shredding.⁵⁵ If volatile solvents are present, such as occurs with pesticides, they should be removed by distillation prior to treatment.⁵⁶

⁴⁸ Additional information is available from CMPS&F – Environment Australia, 1997; Costner, Luscombe and Simpson, 1998; Danish Environmental Protection Agency, 2004; Rahuman, Pistone, Trifirò and Miertu, 2000; UNEP, 1998b; UNEP, 2001; UNEP, 2004b and Vijgen, 2002. See annex V, Bibliography.

⁴⁹ See UNEP, 2004b in annex V, Bibliography.

⁵⁰ See UNEP, 2001 in annex V, Bibliography.

⁵¹ See UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

⁵² See Vijgen, 2002 in annex V, Bibliography.

⁵³ See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000 and UNEP 2001 in annex V, Bibliography.

⁵⁴ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

⁵⁵ See CMPS&F – Environment Australia, 1997 and UNEP 2001, in annex V, Bibliography.

⁵⁶ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

145. *Emissions and residues:* Air emissions are expected to be relatively minor. The potential to form PCDDs and PCDFs during the BCD process is relatively low. However, it has been noted that PCDDs can be formed from chlorophenols under alkaline conditions at temperatures as low as 150°C (Weber, 2004). Other residues produced during the BCD reaction include sludge containing primarily water, salt, unused hydrogen-donor oil and carbon residue. The vendor claims that the carbon residue is inert and non-toxic. For further details, users are referred to the literature produced by BCD Group, Inc.

146. *Release control and post-treatment:* Depending on the type of hydrogen-donor oil used, the slurry residue may be treated in different ways. If No. 6 fuel oil has been used, the sludge may be disposed of as a fuel in a cement kiln. If more refined oils are used, these may be removed from the sludge by gravity or centrifuge separation. The oils can then be reused and the remaining sludge can be further treated for use as a neutralizing agent or disposed of in a landfill.⁵⁷ In addition, BCD plants are equipped with activated carbon traps to minimize releases of volatile organics in gaseous emissions.

147. *Energy requirements:* Energy requirements are expected to be relatively low owing to the low operating temperatures associated with the BCD process.

148. *Material requirements:*

(a) Hydrogen-donor oil, such as No. 6 fuel oil or Sun Par oils No. LW-104, LW-106 and LW-110;

(b) Alkali or alkaline earth metal carbonate, bicarbonate or hydroxide, such as sodium bicarbonate. The amount of alkali required is dependent on the concentration of the halogenated contaminant contained in the medium.⁵⁸ Amounts range from 1 per cent to about 20 per cent by weight of the contaminated medium; and

(c) Proprietary catalyst amounting to 1 per cent by volume of the hydrogen donor oil.

149. The *equipment* associated with this process is thought to be readily available.⁵⁹

150. *Portability:* Modular, transportable and fixed plants have been built.

151. *Health and safety:* In general, the health and safety risks associated with operation of this technology are thought to be low,⁶⁰ although a BCD plant in Melbourne, Australia, was rendered inoperable following a fire in 1995. The fire is thought to have resulted from the operation of a storage vessel without a nitrogen blanket.⁶¹ Some associated pre-treatments such as alkaline pre-treatment of capacitors and solvent extraction have significant fire and explosion risks, although they can be minimized through the application of appropriate precautions.⁶²

152. *Capacity:* BCD can process as much as 2,600 gallons per batch, with a capability of treating two–four batches per day.⁶³

153. *Other practical issues:* Since the BCD process involves stripping chlorine from the waste compound, the treatment process may result in an increased concentration of lower-chlorinated species. This can be of potential concern in the treatment of PCDDs and PCDFs, where the lower-chlorinated congeners are more toxic than the higher-chlorinated congeners. It is therefore important that the process be appropriately monitored to ensure that the reaction continues to completion. In the past, it has been reported that the BCD process was unable to treat high-concentration wastes because of salt build-up.⁶⁴ More recently, however, it has been reported that this problem has been overcome.⁶⁵

154. *State of commercialization:* BCD has been used at two commercial operations within Australia, with one still operating. Another commercial system has been operating in Mexico for the past two years. In addition, BCD systems have been used for short-term projects in Australia, Spain and the United States of America. A BCD unit for the treatment of both soil and pesticide wastes contaminated with PCDDs and PCDFs is now under construction within the Czech Republic.

⁵⁷ See UNEP, 2004b, in annex V, Bibliography.

⁵⁸ See CMPS&F – Environment Australia, 1997 and UNEP 2001 in annex V, Bibliography.

⁵⁹ See Rahuman et al., 2000 in annex V, Bibliography.

⁶⁰ See CMPS&F – Environment Australia, 1997 and Rahuman et al., 2000 in annex V, Bibliography.

⁶¹ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

⁶² Ibid.

⁶³ See Vijgen, 2002 and UNEP, 2004b in annex V, Bibliography.

⁶⁴ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

⁶⁵ See Vijgen, 2002 in annex V, Bibliography.

155. *Vendors:* The patent for this technology is held by BCD Group, Inc., USA (www.bcdinternational.com). BCD Group, Inc. sells licences to operate the technology. Currently, licences are held by companies based in Australia, the Czech Republic, Japan, Mexico and the United States of America.

(c) **Catalytic hydrodechlorination (CHD)**

156. *Process description:* CHD involves the treatment of wastes with hydrogen gas and palladium on carbon (Pd/C) catalyst dispersed in paraffin oil. Hydrogen reacts with chlorine in halogenated waste to produce hydrogen chloride (HCl) and non-halogenated waste. In the case of PCBs, biphenyl is the main product. The process operates at atmospheric pressure and temperatures between 180°C and 260°C (Sakai, Peter and Oono, 2001; Noma, Sakai and Oono, 2002; and Noma, Sakai and Oono, 2003a and 2003b).

157. *Efficiency:* DEs of 99.98–99.9999 per cent have been reported for PCBs. It has also been reported that a reduction of the PCB content to less than 0.5 mg/kg is achievable.

158. *Waste types:* CHD has been demonstrated with PCBs removed from used capacitors. PCDDs and PCDFs contained in PCBs as impurities have also been dechlorinated. A vendor has also claimed that chlorinated wastes in liquid state or dissolved in solvents can be treated by CHD.

159. *Pre-treatment:* PCBs and PCDDs/PCDFs must be extracted using solvents or isolated by vaporization. Substances with low boiling points such as water or alcohols should be removed by distillation prior to treatment.

160. *Emission and residues:* No emissions would occur during the dechlorination reaction because it takes place in the closed hydrogen circulation system. HCl is not discharged from the reaction because it is collected with water as hydrochloric acid within the circulation system. Biphenyl isolated after the reaction by distillation does not contain any toxic materials.

161. *Release control and post-treatment:* Biphenyl, the main product, is separated out from the reaction solvent by distillation after the reaction, and the catalyst and reaction solvent are reused for the next reaction.

162. *Energy requirements:* Energy requirements are expected to be relatively low owing to the low operating temperatures associated with the CHD process.

163. *Material requirements:* The CHD process requires the same number of atoms of hydrogen as those of chlorine in the PCBs, and also 0.5 per cent by weight of catalyst.

164. *Portability:* CHD is available in fixed and transportable configurations depending on the volume of PCBs to be treated.

165. *Health and safety:* The use of hydrogen gas requires adequate controls and safeguards to ensure that explosive air-hydrogen mixtures are not formed.

166. *Capacity:* In Japan, a plant which is capable of treating 2 Mg PCB per day using the CHD process is currently being designed and will be constructed in two years.

167. *Other practical issues:* There are many reports about PCB dechlorination by using CHD. Generally, Pd/C catalyst shows the largest degradation rate compared to the other supported metal catalysts. Reaction temperature can be increased to 260°C when paraffin oil is used as reaction solvent.

168. *State of commercialization:* A company in Japan started to treat capacitors containing or contaminated with PCBs using a CHD plant in 2004. A commercial-scale CHD plant will be in operation in two years in Japan.

169. *Vendor(s):* The patent for this technology is held by Kansai Electric Power Co and Kanden-Engineering Co. (www.kanden-eng.co.jp).

170. *Additional information:* For further information, see the Technical Guideline for Treatment of PCBs in Japan (Japan Industrial Waste Management Foundation, 1999).

(d) **Cement kiln co-incineration**⁶⁶

171. *Process description:* Cement kilns typically consist of a long cylinder of 50–150 metres, inclined slightly from the horizontal (3 per cent to 4 per cent gradient), which is rotated at about 1-4 revolutions per minute. Raw materials such as limestone, silica, alumina and iron oxides are fed into the upper or “cold” end of the rotary kiln. The slope and rotation cause the materials to move toward the lower or “hot” end of the kiln. The kiln is fired at the lower end of the kiln, where temperatures reach 1,400°C–1,500°C. As the materials move through the kiln, they undergo drying and pyroprocessing reactions to form clinker.

172. *Efficiency:* DREs of greater than 99.99998 per cent have been reported for PCBs in several countries (Ahling, 1979; Benestad, 1989; Lauber, 1987; Mantus, 1992. US-EPA, 1986; Lauber, 1982; von Krogbeumker, 1994; Black, 1983).

173. *Waste types:* As mentioned above, cement kilns have been demonstrated with PCBs, but should be applicable to other POPs. Cement kilns are capable of treating both liquid and solid wastes.⁶⁷

174. *Pre-treatment:* Pre-treatment can involve:

- (a) Thermal desorption of solid wastes;
- (b) Homogenization of solid and liquid wastes through drying, shredding, mixing and grinding.

175. *Emissions and residues:* Emissions may include, inter alia, nitrogen oxides, carbon monoxide, sulphur dioxide and other oxides of sulphur, metals and their compounds, hydrogen chloride, hydrogen fluoride, ammonia, PCDDs, PCDFs, benzene, toluene, xylene, polycyclic aromatic hydrocarbons, chlorobenzenes and PCBs.⁶⁸ It should be noted, however, that cement kilns can comply with PCDD and PCDF air emission levels below 0.1 ng TEQ/Nm³.⁶⁹ Residues include cement kiln dust captured by the air pollution control system.

176. *Release control and post-treatment:* Process gases require treatment to remove cement kiln dust and organic compounds, sulphur dioxide, nitrogen oxide and also heat so that formation of PCDDs and PCDFs is minimized. Treatments include use of preheaters, electrostatic precipitators, fabric filters and activated carbon filters.⁷⁰ It has been reported that PCDD and PCDF concentrations within cement kiln dusts range between 0.4 and 2.6 mg/kg.^{71,72} Accordingly, recovered cement kiln dusts should be put back into kilns to the maximum extent practicable, while the remainder may require disposal in a specially engineered landfill or permanent storage in an underground mine or formation.

177. *Energy requirements:* New kiln systems with five cyclone preheater stages and precalciner will require an average of 2,900–3,200 MJ to produce 1 Mg of clinker.⁷³

178. *Material requirements:* Cement manufacturing requires large amounts of materials, including limestone, silica, alumina, iron oxides and gypsum.⁷⁴

179. *Portability:* Cement kilns are available only in fixed configurations.

180. *Health and safety:* Treatment of wastes within cement kilns can be regarded as relatively safe if properly designed and operated.⁷⁵

⁶⁶ Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Danish Environmental Protection Agency, 2004; Karstensen, 2001; Rahuman et al., 2000; Stobiecki et al., 2001 and UNEP, 1998b. In addition, information on BAT and BEP with respect to cement kilns firing hazardous waste is available from the European Commission, 2001 and UNEP 2004a. See annex V, Bibliography.

⁶⁷ See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000 and UNEP, 2004c in annex V, Bibliography.

⁶⁸ See UNEP, 2004c in annex V, Bibliography.

⁶⁹ See UNEP, 2004c in annex V, Bibliography.

⁷⁰ See CMPS&F – Environment Australia, 1997; Karstensen, 2006 and UNEP, 2004c in annex V, Bibliography.

⁷¹ TEQ were not given.

⁷² See UNEP 2004a in annex V, Bibliography.

⁷³ Ibid.

⁷⁴ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

⁷⁵ Ibid.

181. *Capacity:* Cement kilns co-incinerating wastes as a fuel are normally limited to a maximum of 40 per cent of the heat requirement in the form of hazardous waste.⁷⁶ It has been noted, however, that cement kilns with high throughput can potentially treat significant quantities of waste.⁷⁷

182. *Other practical issues:* Cement kilns treating wastes may require modifications to the rotary kiln.⁷⁸ Potential feed points for supplying fuel to the kiln system are:

- (a) The main burner at the rotary kiln outlet end;
- (b) A feed chute at the transition chamber at the rotary kiln inlet end (for lump fuel);
- (c) Secondary burners to the riser duct;
- (d) Precalciner burners to the precalciner;
- (e) A feed chute to the precalciner/preheater (for lump fuel);
- (f) A mid-kiln valve in the case of long wet and dry kilns (for lump fuel) (UNEP, 2004c).

183. Chlorides have an impact on the quality of the cement and so have to be limited. Chlorine can be found in all the raw materials used in cement manufacture, so the chlorine levels in the hazardous waste can be critical. However, if they are blended down sufficiently, cement kilns can treat highly chlorinated hazardous waste.

184. *State of commercialization:* Cement kilns in the United States of America, some European and a number of developing countries have been used to treat wastes contaminated with POPs (World Business Council, 2004: Formation and Release of POPs in the Cement Industry, Kartensen, 2006).

185. *Vendors:* A number of existing cement kiln co-incineration operations are identified in the inventory of worldwide PCB destruction capacity.⁷⁹

(e) **Gas-phase chemical reduction (GPCR)**⁸⁰

186. *Process description:* The GPCR process involves the thermochemical reduction of organic compounds. At temperatures greater than 850°C and at low pressures, hydrogen reacts with chlorinated organic compounds to yield primarily methane and hydrogen chloride.

187. *Efficiency:* DEs of 99.9999 per cent have been reported for DDT, HCB, PCBs, PCDDs and PCDFs.⁸¹

188. *Waste types:* In addition to the substances listed above, GPCR should also be capable of treating wastes consisting of, containing or contaminated with all other POPs.⁸² GPCR is capable of treating wastes with a high POP concentration,⁸³ including aqueous and oily liquids, soils, sediments, transformers and capacitors.⁸⁴

189. *Pre-treatment:* Depending on the waste type, one of the following three pre-treatment units is used to volatilize wastes prior to treatment in the GPCR reactor:

- (a) Thermal reduction batch processor (TRBP) for bulk solids, including those in drums;
- (b) Torbed reactor for contaminated soils and sediments, but also adapted for liquids;
- (c) Liquid waste pre-heater system (LWPS) for liquids.⁸⁵

⁷⁶ See UNEP, 2004c in annex V, Bibliography.

⁷⁷ See UNEP, 1998b in annex V, Bibliography.

⁷⁸ See CMPS&F – Environment Australia, 1997 and UNEP, 2004c in annex V, Bibliography.

⁷⁹ See UNEP, 1998b in annex V, Bibliography.

⁸⁰ Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Danish Environmental Protection Agency, 2004; Kümmling, Gray, Power and Woodland, 2001; Rahuman et al., 2000; Ray, 2001; UNEP, 2001; UNEP, 2004b; and Vijgen, 2002. See annex V, Bibliography.

⁸¹ See CMPS&F – Environment Australia, 1997; Kümmling, 2001; Rahuman et al., 2000; UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

⁸² See CMPS&F – Environment Australia, 1997; UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

⁸³ See UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

⁸⁴ See CMPS&F – Environment Australia, 1997; UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

⁸⁵ See CMPS&F – Environment Australia, 1997; Kümmling et al., 2001; UNEP, 2001; UNEP, 2004b and Vijgen, 2004 in annex V, Bibliography.

190. In addition, other pre-processing is required for large capacitors and building rubble. Large capacitors are punctured and drained, while rubble and concrete must be reduced in size to less than one square metre.⁸⁶

191. *Emissions and residues:* In addition to hydrogen chloride and methane, low molecular weight hydrocarbons may be emitted. Residues from the GPCR process include used liquor and water. Solid residues will also be generated from solid waste inputs.⁸⁷ Since the GPCR process takes place in a reducing atmosphere, the possibility of PCDD and PCDF formation is considered limited.⁸⁸

192. *Release control and post-treatment:* Gases leaving the reactor are scrubbed to remove water, heat, acid and carbon dioxide.⁸⁹ Scrubber residue and particulate will require disposal off site.⁹⁰ Solid residues generated from solid waste inputs should be suitable for disposal in a landfill.⁹¹

193. *Energy requirements:* Methane produced during the process can provide much of the fuel needs.⁹² It has been reported that electricity requirements range from 96 kWh per ton of soil treated to around 900 kWh per ton of pure organic contaminants treated.⁹³

194. *Material requirements:* There is a need for hydrogen supplies, at least during start-up. It has been reported that methane produced during the GPCR process can be used to form enough hydrogen to operate the process thereafter.⁹⁴ The hydrogen production unit was plagued, however, by reliability problems in the past.⁹⁵ Other material requirements include caustic for the acid scrubber.⁹⁶

195. *Portability:* GPCR is available in fixed and transportable configurations.⁹⁷

196. *Health and safety:* Use of hydrogen gas under pressure requires suitable controls and safeguards to ensure that explosive air-hydrogen mixtures are not formed.⁹⁸ Operating experience gained to date has indicated that the GPCR process can be undertaken safely.⁹⁹

197. *Capacity:* GPCR process capacity is dependent on the capacity of the three pre-treatment units, as specified below:

(a) TRBP has a capacity of up to 100 tons of solids per month or up to four litres per minute of liquids. Two TRBPs can be used in parallel to double capacity;

(b) Torbed reactor has a capacity of up to 5,000 tons of soils and sediments per month, although this pre-treatment unit is still in the development stage; and

(c) LWPS has a capacity of three litres per minute.¹⁰⁰

198. *Other practical issues:* Contaminants such as sulphur and arsenic were found to inhibit treatment in earlier development stages, although it is unclear whether this problem is still encountered.¹⁰¹

199. *State of commercialization:* Commercial-scale GPCR plants have operated in Canada and Australia. The GPCR plant in Australia has operated for more than five years. In addition, a GPCR plant has recently been authorized in Japan.¹⁰²

⁸⁶ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

⁸⁷ See UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

⁸⁸ See CMPS&F – Environment Australia, 1997 and Rahuman et al., 2000 in annex V, Bibliography.

⁸⁹ See Kümmling et al., 2001; CMPS&F – Environment Australia, 1997 and Rahuman et al., 2000 in annex V, Bibliography.

⁹⁰ See Rahuman et al., 2000 and Vijgen, 2002 in annex V, Bibliography.

⁹¹ See UNEP, 2004b in annex V, Bibliography.

⁹² See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000; UNEP, 2001; UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

⁹³ CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

⁹⁴ See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000; UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

⁹⁵ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

⁹⁶ See UNEP, 2004b in annex V, Bibliography.

⁹⁷ See UNEP, 2001; UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

⁹⁸ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

⁹⁹ See CMPS&F – Environment Australia, 1997 and UNEP, 2004b in annex V, Bibliography.

¹⁰⁰ See UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

¹⁰¹ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

200. *Vendors*: The patent for this technology is held by the sole supplier, ELI Eco Logic International Inc. (www.ecologic.ca). ELI Eco Logic International Inc. sells licences to operate the technology.

(f) **Hazardous-waste incineration**¹⁰³

201. *Process description*: Hazardous-waste incineration uses controlled flame combustion to treat organic contaminants, mainly in rotary kilns. Typically, a process for treatment involves heating to a temperature greater than 850°C or, if the chlorine content is above 1 per cent, greater than 1,100°C, with a residence time greater than two seconds, under conditions that assure appropriate mixing. Dedicated hazardous-waste incinerators are available in a number of configurations, including rotary kiln incinerators, and static ovens (for liquids only). High-efficiency boilers and lightweight aggregate kilns are also used for the co-incineration of hazardous wastes. (See Brunner, 2004, for additional information regarding the application of these technologies.)

202. *Efficiency*: DREs of greater than 99.9999 per cent have been reported for treatment of wastes consisting of, containing or contaminated with POPs.¹⁰⁴ DEs of greater than 99.999 and DREs of greater than 99.9999 per cent have been reported for aldrin, chlordane and DDT (Ministry of the Environment of Japan, 2004), while DEs between 83.15 and 99.88 per cent have been reported for PCBs (EPA, 1990).

203. *Waste types*: As noted above, hazardous-waste incinerators are capable of treating wastes consisting of, containing or contaminated with any POP. Incinerators can be designed to accept wastes in any concentration or any physical form, i.e., gases, liquids, solids, sludges and slurries.¹⁰⁵

204. *Pre-treatment*: Depending upon the configuration, pre-treatment requirements may include blending, dewatering and size reduction of wastes.¹⁰⁶

205. *Emissions and residues*: Emissions include carbon monoxide, carbon dioxide, HCB, hydrogen chloride, particulates, PCDDs, PCDFs and PCBs and water vapour.¹⁰⁷ Incinerators applying BAT, inter alia, designed for high temperature and equipped with prevention of reformation of PCDDs and PCDFs and dedicated PCDD and PCDF removal (e.g., activated carbon filters), have led to very low PCDD and PCDF emissions to air and discharges to water.¹⁰⁸ In the residues, PCDDs and PCDFs are mainly found in fly ash and salt, and to some extent in bottom ash and scrubber water sludge.

206. *Release control and post-treatment*: Process gases may require treatment to remove hydrogen chloride and particulate matter and to prevent the formation of and remove unintentionally produced POPs. This can be achieved through a combination of types of post-treatments, including cyclones and multi-cyclones, electrostatic filters, static bed filters, scrubbers, selective catalytic reduction, rapid quenching systems and carbon adsorption.¹⁰⁹ Depending upon their characteristics, bottom and fly ashes may require disposal within a specially engineered landfill.¹¹⁰

207. *Energy requirements*: The amount of combustion fuel required will depend upon the composition and calorific value of the waste.

208. *Material requirements*: Material requirements include cooling water and lime or another suitable material for removal of acid gases.

209. *Portability*: Hazardous waste incinerators are available in both portable and fixed units.

210. *Health and safety*: Health and safety hazards include those associated with high operating temperatures.¹¹¹

¹⁰² See CMPS&F – Environment Australia, 1997; Kümmling et al., 2001; Ray, 2001; UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

¹⁰³ Additional information is available from Danish Environmental Protection Agency, 2004; Federal Remediation Technologies Roundtable (FRTR), 2002; Rahuman et al., 2000; UNEP, 1995c; UNEP, 1998b; UNEP, 2001 and United States Army Corps of Engineers, 2003. In addition, information on BAT and BEP with respect to hazardous waste incinerators is available from the European Commission 2004 and UNEP 2006. See annex V, Bibliography.

¹⁰⁴ See FRTR, 2002; Rahuman et al., 2000; UNEP, 1998b and UNEP, 2001 in annex V, Bibliography.

¹⁰⁵ See UNEP, 1995c in annex V, Bibliography.

¹⁰⁶ See UNEP, 1995c; UNEP, 1998b and UNEP, 2004c in annex V, Bibliography.

¹⁰⁷ See UNEP, 1995c; UNEP, 1998b and UNEP, 2004c in annex V, Bibliography.

¹⁰⁸ UNEP, 2001 in annex V, Bibliography.

¹⁰⁹ UNEP, 2004c.

¹¹⁰ See United States Army Corps of Engineers, 2003 in annex V, Bibliography.

¹¹¹ Ibid.

211. *Capacity*: Hazardous-waste incinerators can treat between 30,000 and 100,000 tons per year.¹¹²
212. *Other practical issues*: None to report at this time.
213. *State of commercialization*: There is a long history of experience with hazardous waste incineration.¹¹³
214. *Vendors*: A number of existing hazardous-waste incineration facilities are identified within the inventory of worldwide PCB destruction capacity.¹¹⁴

(g) Photochemical dechlorination (PCD) and catalytic dechlorination (CD) reaction

215. *Process description*: PCD and CD is a technology using the combined methods of both photochemical dechlorination (PCD) reaction and catalytic dechlorination (CD) reaction (Watanabe, Ohara and Tajima, 2002 and Watanabe, Ohara, Tarima, Yoneki and Hosya, 2003). In the destruction process, PCBs are mixed with sodium hydroxide (NaOH) and isopropyl alcohol (IPA) so that the PCB concentration in the IPA should reach several per cent by weight. Subsequently, PCBs are dechlorinated by two independent processes, i.e., PCD and CD processes. Each process is operated at moderate temperature (< 75°C) and atmospheric pressure. After the PCBs are dechlorinated, biphenyl, sodium chloride, acetone and water are generated, but no gases such as hydrogen or hydrochloric acid gas are produced.
216. *Efficiency*: DEs of 99.99–99.9999 per cent have been achieved for PCBs and 99.9999–99.999999 per cent for PCDDs and PCDFs (Tajima et al., 2003; and Watanabe et al., 2003).
217. *Waste types*: The PCD and CD process has been demonstrated to treat oil from transformers and capacitors containing PCBs at high concentrations and contaminated with PCDDs and PCDFs, and should be applicable to other POPs as well. Soils and sludge are not treatable with this technology. PCB in clothing, packaging, wood and other multi-porous materials should be extracted by solvent.
218. *Pretreatment*: Electrical equipment contaminated with PCBs requires some pre-treatment. After removing PCBs from the equipment, the contaminated material such as cases, coils and insulation papers are disassembled and separated. PCBs are extracted from those materials by a hydrocarbon washing agent such as decane. PCBs and the solvent are separated by the distiller. Distilled PCBs and solvent are destroyed by the PCD and CD processes respectively. The solvent is reused for washing. It is not necessary to pre-treat soils, sludge and water.
219. *Potential emissions and residues*: Air emissions are expected to be relatively minor. The potential for PCDDs and PCDFs to be formed during the PCD and CD processes is not considered theoretically possible. Residues include solid sodium chloride and used catalyst (Watanabe et al., 2002; Watanabe et al., 2003).
220. *Post-treatment*: A distiller separates IPA from the solution, and large fractions of the IPA can be recycled several times as a solvent of PCBs. Wastes generated from the processes include biphenyl, sodium chloride, acetone, water and residual IPA. Sodium chloride is removed from the solution by filtration and disposed of to landfill. The used catalyst is washed with water in order to remove sodium chloride, and can be reused several times for the CD process.
221. *Energy requirements*: The PCD process requires 3 MJ/kg PCB for mercury lamps. The energy requirement is expected to be relatively low owing to the low operating temperatures (75°C) associated with the PCD and CD process (Watanabe et al., 2002; Watanabe et al., 2003).
222. *Material requirements*:
- (a) Alkali: NaOH (NaOH/Cl = 1:3);
 - (b) Catalyst: 2 kg/m³ by volume of the hydrogen donor;
 - (c) Hydrogen donor: IPA.
223. *Portability*: Modular, transportable plants should be available. A fixed plant has been established in Kawasaki, Japan.
224. *Health and safety*: In general, the health and safety risks associated with operation of this technology are regarded as low (Watanabe et al., 2002; Watanabe et al., 2003; Sasaki et al., 2003).

¹¹² See UNEP, 2004c in annex V, Bibliography.

¹¹³ See UNEP, 2001 in annex V, Bibliography.

¹¹⁴ See UNEP, 1998 in annex V, Bibliography.

225. *Capacity*: The PCD and CD technology is available with a capacity of 50 kg oil per day by one unit. The capacity could be flexible owing to the size of facility (e.g., either lower than or as high as 2 ton/day)

226. *Other practical issues*: The PCD and CD method is especially suitable for pure PCB. This technology satisfies the stringent release standards in Japan (PCBs in the waste oil < 0.5 mg/kg).

227. *State of commercialization*: The PCD and CD technologies have been operated in Kawasaki, Japan, for the past two years (Watanabe et al., 2002; and Watanabe et al., 2003).

228. *Vendor(s)*: The patent and all rights for this technology are held and reserved by Toshiba Corporation (www.toshiba.co.jp/efort/market/pcb/index_j.htm). Toshiba Corporation sells licenses for operation of the technology.

229. *Additional information*: For further information, see the Technical Guideline for treatment of PCBs in Japan (Japan Industrial Waste Management Foundation, 1999) and also Watanabe et al., 2002; Watanabe et al., 2003; Sasaki et al., 2003; Noma et al., 2002; and Noma et al., 2003.

(h) Plasma arc¹¹⁵

230. *Process description*: The Plascon™ process uses a plasma arc with temperatures in excess of 3,000°C to pyrolyse wastes. Together with argon, wastes are injected directly into the plasma arc. The high temperature causes compounds to dissociate into their elemental ions and atoms. Recombination occurs in a cooler area of the reaction chamber, followed by a quench, resulting in the formation of simple molecules.¹¹⁶

231. *Efficiency*: Bench-scale tests with oils containing 60 per cent PCBs have achieved DREs ranging from 99.9999 to 99.999999 per cent.¹¹⁷

232. *Waste types*: In addition to PCB oils, a Plascon™ plant in Australia has recently been configured to treat pesticide wastes.¹¹⁸ Waste types to be treated must be liquid or gas, or solid if in the form of a fine slurry which can be pumped. Very viscous liquids or sludges thicker than 30–40 weight motor oil cannot be processed without pre-treatment. Other solid wastes cannot be treated unless some form of pre-treatment is undertaken.¹¹⁹

233. *Pre-treatment*: Pre-treatment is not required for most liquids. Solids such as contaminated soils, capacitors and transformers can be pre-treated using thermal desorption or solvent extraction.¹²⁰

234. *Emissions and residues*: Emissions include gases consisting of argon, carbon dioxide and water vapour. Residues include an aqueous solution of inorganic sodium salts, such as sodium chloride, sodium bicarbonate and sodium fluoride. Bench-scale tests with PCBs showed PCDD levels in scrubber water and stack gases in the part per trillion (ppt) range.¹²¹ At a Plascon™ plant in Australia, used to treat a variety of wastes, the level of PCBs in the effluent discharged complies with a 2 ppb limit.¹²² POP concentrations in solid residues are unknown.¹²³

235. *Release control and post-treatment*: Currently, there is little information available regarding post-treatment requirements.

236. *Energy requirements*: A 150 kW Plascon™ unit requires 1,000–3,000 kWh of electricity per tonne of waste.¹²⁴

237. *Material requirements*: Currently, there is little information available regarding material requirements. It has been noted, however, that this process does require argon gas, oxygen gas, caustic and cooling water.¹²⁵

¹¹⁵ Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Rahuman et al., 2000; Ray, 2001; UNEP, 1998b; UNEP, 2000b; UNEP, 2001 and UNEP, 2004b. See annex V, Bibliography.

¹¹⁶ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

¹¹⁷ See Rahuman et al., 2000 and UNEP, 2004b in annex V, Bibliography.

¹¹⁸ See UNEP, 2004b in annex V, Bibliography.

¹¹⁹ See CMPS&F – Environment Australia, 1997 and UNEP, 2004b in annex V, Bibliography.

¹²⁰ Ibid.

¹²¹ See CMPS&F – Environment Australia, 1997 and Rahuman et al., 2000 in annex V, Bibliography.

¹²² See UNEP, 2004b in annex V, Bibliography.

¹²³ Ibid.

¹²⁴ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

238. *Portability*: Plascon™ is available in transportable and fixed units.¹²⁶
239. *Health and safety*: Since the Plascon™ process has a low throughput, there is a low risk associated with release of partially treated wastes following process failure.¹²⁷ Currently, there is little additional information available regarding health and safety.
240. *Capacity*: A 150 kW Plascon™ unit can process 1–3 tons per day of waste.¹²⁸
241. *Other practical issues*: It should be noted that metals or metal-like compounds (e.g., arsenic) may interfere with catalysts or cause problems in disposing of the residue. For example, arsenicals in pesticide waste exported from Pacific islands for disposal in Australia using the Plascon™ process have presented a particular problem for that project.
242. *State of commercialization*: BCD Technologies operates two plasma plants in Australia: one in Brisbane for PCBs and POPs and another in Melbourne for treating CFCs and halons. BCD Technologies also operates a BCD plant for low-level PCBs and POPs and also has two thermal desorbers for treating contaminated solids. Mitsubishi Chemical Corporation has installed a Plascon™ plant in Japan to treat wastes consisting of, containing or contaminated with PCBs.
243. *Vendors*: The vendor for the Plascon™ process is SRL Plasma Pty Ltd., Narangba, Australia (www.srlplasma.com.au) and the Commonwealth Scientific Industrial Research Organization (CSIRO). The three patents for Plascon™ are jointly owned by SRL Plasma Pty Ltd. and CSIRO.

(i) Potassium tert-Butoxide (t-BuOK) method

244. *Process description*: PCBs in insulating oils are dechlorinated by reaction with potassium tert-butoxide (t-BuOK). t-BuOK reacts with chlorine in PCBs to produce salt and non-chlorinated waste. Typically, the process operates at atmospheric pressure and temperatures between 200°C and 240°C (Oono, Kaneda and Kirata, 1997 and Oono and Kaneda, 1997).
245. *Efficiency*: DEs of 99.98–99.9999 per cent have been reported for PCBs. It has also been reported that a reduction of the PCB content to less than 0.5 mg/kg is achievable.
246. *Waste types*: The t-BuOK method has been demonstrated with low-contaminated mineral oils. A vendor has also claimed that the chlorinated wastes in liquid state or dissolved in solvents can be treated by the t-BuOK method.
247. *Pretreatment*: t-BuOK reacts with water to produce potassium hydroxide and tert-butanol. If a high volume of water is contained in the mineral oils contaminated with PCBs, t-BuOK will react more easily with the water than with the chlorine in PCBs. Therefore, water in the oils should be removed before the reaction.
248. *Emissions and residues*: No emission would occur during the reaction. There is little potential for PCDDs and PCDFs to be formed as by-products during the reaction owing to the very fast dechlorination rate, which causes chlorine to be released quickly (Takigami, Sakai and Oono, 2002a and 2002b).
249. *Release control and post-treatment*: By-products can be separated out from the oils by washing with water after the reaction. The decontaminated oils can be reused as fuel.
250. *Energy requirements*: Energy requirements are expected to be relatively low owing to the low operating temperatures associated with t-BuOK process.
251. *Material requirements*: When the PCB content in the mineral oils is below 200 ppm, the amount of t-BuOK required is about 0.5 per cent by weight of the contaminated oils.
252. *Portability*: This process is available in fixed and transportable configurations depending on the volume of the contaminated oil to be treated.
253. *Health and safety*: In general, the health and safety risks associated with the operation of this technology are considered to be low.
254. *Capacity*: It has been reported that 36,000 litres per day of contaminated oil have been treated in Japan using this technology.

¹²⁵ See CMPS&F – Environment Australia, 1997 and UNEP, 2004b in annex V, Bibliography.

¹²⁶ See UNEP, 2004b in annex V, Bibliography.

¹²⁷ See CMPS&F – Environment Australia, 1997 and UNEP, 2004b in annex V, Bibliography.

¹²⁸ Ibid.

255. *Other practical issues:* It is possible to treat a large amount of contaminated oils in a short period of time with this technology, as it can be operated continuously.

256. *State of commercialization:* A company in Japan has been treating contaminated mineral oils since 2004 in a continuously operated plant.

257. *Vendor(s):* The patent for this technology is held by Kansai Electric Power Co and Kanden-Engineering Co. (www.kanden-eng.co.jp).

258. *Additional information:* For further information see the Technical Guideline for treatment of PCBs in Japan (Japan Industrial Waste Management Foundation, 1999).

(j) Supercritical water oxidation (SCWO) and subcritical water oxidation¹²⁹

259. *Process description:* SCWO and subcritical water oxidation treat wastes in an enclosed system using an oxidant (such as oxygen, hydrogen peroxide, nitrite, nitrate, etc.) in water at temperatures and pressures above the critical point of water (374°C and 218 atmospheres) and below subcritical conditions (370°C and 262 atmospheres). Under these conditions, organic materials become highly soluble in water and are oxidized to produce carbon dioxide, water and inorganic acids or salts.

260. *Efficiency:* DEs of greater than 99.999 per cent and DREs of greater than 99.9999 per cent have been reported for aldrin, chlordane and PCBs for SCWO (Ministry of the Environment of Japan, 2004). DEs of greater than 99.999999 and DREs of greater than 99.9999999 per cent have been reported for subcritical water oxidation (Ministry of the Environment of Japan, 2004). DREs as high as 99.9999 per cent have also been demonstrated for PCDDs in bench-scale tests.¹³⁰

261. *Waste types:* SCWO and subcritical water oxidation are thought to be applicable to all POPs¹³¹ (Japan Industrial Waste Management Foundation, 1999). Applicable waste types include aqueous wastes, oils, solvents and solids with a diameter of under 200 µm. The organic content of the waste is limited to below 20 per cent.¹³²

262. *Pre-treatment:* Concentrated wastes may have to be diluted prior to treatment in order to reduce the organic content to below 20 per cent. In the case of subcritical water oxidation, dilution of wastes is not necessary. If solids are present, they must be reduced to under 200 µm in diameter.

263. *Emissions and residues:* During laboratory-scale PCB destruction, it was shown that the SCWO technology has the potential to form high concentrations of PCDFs (in the per cent range) during PCB degradation even at temperatures of practical operation (Weber, 2004). It has been reported that emissions contain no oxides of nitrogen or acid gases such as hydrogen chloride or oxides of sulphur and that process residues consist of water and solids if the waste contains inorganic salts or organic compounds with halogens, sulphur or phosphorus.¹³³ Limited information has been reported regarding potential concentrations of undestroyed chemicals.¹³⁴ The process is designed so that emissions and residues can be captured for reprocessing if needed.¹³⁵

264. *Release control and post-treatment:* Currently, there is no specific information available regarding post-treatment requirements.

265. *Energy requirements:* Energy requirements are expected to be relatively high because of the combinations of high temperatures and pressures. It has been claimed, however, that as long as relatively high hydrocarbon content is present in the feed, no energy input is required to heat the feed to supercritical temperatures.¹³⁶

266. *Material requirements:* The SCWO and subcritical water oxidation reaction vessel must be constructed of materials capable of resisting corrosion caused by halogen ions.¹³⁷ Material corrosion can be severe at the temperatures and pressures used in the SCWO and subcritical water oxidation process.

¹²⁹ Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Rahuman et al., 2000; UNEP, 2001 and UNEP, 2004b. See annex V, Bibliography.

¹³⁰ See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000 and Vijgen, 2002 in annex V, Bibliography.

¹³¹ See UNEP, 2004b in annex V, Bibliography.

¹³² See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000 and Vijgen, 2002 in annex V, Bibliography.

¹³³ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

¹³⁴ See CMPS&F – Environment Australia, 1997 and UNEP, 2004b in annex V, Bibliography.

¹³⁵ See UNEP, 2004b in annex V, Bibliography.

¹³⁶ See Rahuman et al., 2000 in annex V, Bibliography.

¹³⁷ See Vijgen, 2002 in annex V, Bibliography.

In the past, the use of titanium alloys has been proposed to tackle this problem. Current vendors claim to have overcome this problem through the use of advanced materials and engineering designs.¹³⁸

267. *Portability*: The SCWO and subcritical water oxidation units are currently used in a fixed configuration, but are thought to be transportable.¹³⁹

268. *Health and safety*: The high temperatures and pressures used in this process require special safety precautions.¹⁴⁰

269. *Capacity*: Current SCWO demonstration units are capable of treating 500 kg/h, while full-scale units will be designed to treat 2,700 kg/h.¹⁴¹

270. *Other practical issues*: Earlier designs were plagued by reliability, corrosion and plugging problems. Current vendors claim to have addressed these problems through the use of special reactor designs and corrosion-resistant materials.¹⁴²

271. *State of commercialization*: A full-scale commercial plant has recently begun to operate in Japan. In addition, the SCWO process has been approved for full-scale development and use in the chemical-weapon destruction programme of the United States of America.

272. *Vendors*: Firms providing this service include:

- (a) Foster Wheeler Development Corporation (www.fosterwheeler.com);
- (b) General Atomics (www.ga.com);
- (c) Mitsubishi Heavy Industries, Ltd. (www.mhi.co.jp).

(k) Thermal and metallurgical production of metals

273. *Process description*: The processes described below are primarily designed for the recovery of iron and non-ferrous metals (NFM) e.g. aluminium, copper, zinc, lead and nickel from ore concentrates as well as from secondary raw materials (intermediates, wastes). However, due to the nature of the processes they are in some cases also used on a commercial basis for the destruction of the POP content of appropriate wastes (see paragraph 275). A general description of some of the following processes may also be found in the European BAT reference documents:^{143, 144}:

(a) Processes which are relevant for the destruction of the POP content in iron-containing wastes use certain types of blast furnace, shaft furnace or hearth furnace. All these processes operate under reducing atmospheres at high temperatures (1,200°C–1,450°C). The high temperature and the reducing atmosphere destroy PCDDs and PCDFs contained in the wastes and avoid de novo synthesis. The blast furnace and the shaft furnace processes use coke and small amounts of other reducing agents to reduce the iron-containing input to cast iron. There are no direct emissions of process gas as it is used as a secondary fuel. In the hearth furnace process, the iron-containing material is charged to a multi-hearth furnace together with coal. The iron oxide is directly reduced to solid direct reduced iron (DRI). In a second step the reduced iron is melted in an electric arc furnace to produce cast iron;

(b) Processes which are relevant for the destruction of the POP content in wastes containing NFMs are the Waelz rotary kiln process and bath melting processes using vertical or horizontal furnaces. These processes are reductive, reach temperatures of 1,200°C and use rapid quenching thus PCDDs and PCDFs are destroyed and de novo synthesis is avoided. In the Waelz process zinc-containing steel mill dusts, sludges, filter cakes, etc. are pelletized and smelted together with a reductant. At temperatures of 1,200°C, the zinc volatilizes and is oxidized to “Waelz Oxide”, which is collected in a filter unit. In the vertical bath furnace process, copper-containing residues are smelted at temperatures of at least 1,200°C. The filter dust is used for the production of zinc and zinc compounds. In the horizontal bath furnace process, lead-containing residues and ore concentrates are charged continuously into a smelting bath which has an oxidizing and a reducing zone with temperatures between 1,000°C and 1,200°C. The process gas (sulphur dioxide concentration above 10 per cent) is used for sulphuric acid production after heat recovery and de-dusting. The dust from the process is recycled after cadmium leaching.

¹³⁸ Ibid.

¹³⁹ See UNEP, 2004b and Vijgen, 2004 in annex V, Bibliography.

¹⁴⁰ See CMPS&F – Environment Australia, 1997 in annex V, Bibliography.

¹⁴¹ See UNEP, 2004b and Vijgen, 2002 in annex V, Bibliography.

¹⁴² Ibid.

¹⁴³ European Commission, 2001a in annex V, Bibliography

¹⁴⁴ European Commission, 2001b in annex V, Bibliography

274. *Efficiency:* Data on DE or DRE are not available.
275. *Waste types:* The processes described in paragraph 273 above are specific to the treatment of the following wastes:
- (a) Residues from iron- and steel-making processes such as dusts or sludges from gas treatment or mill scale that may be contaminated with PCDDs and PCDFs;
 - (b) Zinc-containing filter dusts from steelworks, dusts from gas cleaning systems of copper smelters etc. and lead-containing leaching residues of NMF production that may be contaminated with PCDDs and PCDFs.
276. *Pre-treatment:* Iron-containing materials recycled by the conventional blast furnace process require pre-treatment in an agglomeration plant. For the shaft furnace (“Oxycup” furnace) process the iron-containing waste is briquetted. This is a cold process in which a binder and water is added to the fines, which are then pressed to briquettes, dried and hardened. Generally no pre-treatment is necessary for the multi-hearth furnace process, although under in some special cases the fine solids may have to be pelletized. This involves only the addition of water and the formation of pellets in a drum. Special pre-treatment of materials contaminated with POPs is not usually necessary for NFM.
277. *Emissions and residues:* In iron and NFM production PCDDs and PCDFs may be formed within the process or downstream in the flue gas treatment system. Application of BAT should, however, prevent or at least minimize such emissions. Where the processes described in paragraph 273 above are used for the destruction of the POPs content in wastes appropriate release control and post-treatment techniques are required (see paragraph 278 below). When such techniques are employed, air emissions of PCDDs and PCDFs from these processes are below 0.1 ng TEQ/Nm³. Slags are in many cases used for construction purposes. For iron metals, emissions can occur from pre-treatment in an agglomeration plant and also in the off-gas from the melting furnace. Residues from de-dusting systems are mainly used in the NFM industry. The off-gas of the multi-hearth furnace is de-dusted by a cyclone, underlies a post-combustion, is quenched and cleaned by addition of adsorbent and a bag filter. The off-gas of the melting furnace also underlies a post-combustion and is quenched before it is mixed up with the off-gas of the multi-hearth furnace for the joint adsorbance step. For NFM, residues include filter dusts and sludges from waste water treatment.
278. *Release control and post-treatment:* Control of temperatures and rapid quenching are often suitable means of minimizing PCDD and PCDF formation. Process gases require treatment to remove dust which consists mainly of metals or metal oxides as well as sulphur dioxide when smelting sulphidic materials. In the ferrous metals industry waste gases from agglomeration plants are treated by an electrostatic precipitator followed by further flue gas treatment, e.g., adsorption techniques followed by an additional bag filter. The off-gases from multi-hearth furnaces are de-dusted by a cyclone and subjected to treatment by post-combustion, quenching and further cleaning by addition of adsorbent followed by a bag filter. The off-gases from the associated melting furnaces also require post-combustion and quenching and are then combined with the off-gas stream from the multi-hearth furnaces for further treatment by addition of adsorbent followed by a bag filter. In NFM production suitable treatment techniques include, inter alia, the use of fabric filters, electrostatic precipitators or scrubbers, sulphuric acid plants or adsorption techniques with activated carbon.
279. *Energy requirements:* Production processes for iron and NFM are energy-intensive with significant differences between different metals. The treatment of the POP content in wastes within these processes requires little additional energy.
280. *Material requirements:* For production of metals, raw materials (ores, concentrates or secondary material) are used as well as additives (e.g., sand, limestone), reductants (coal and coke) and fuels (oil and gas). Temperature control to avoid de novo synthesis of PCDDs and PCDFs requires additional water for quenching.
281. *Portability:* Metal smelters are large and fixed installations.
282. *Health and safety:* The treatment of wastes within thermal processes can be regarded as safe if properly designed and operated.
283. *Capacity:* Metal smelters described above have feedstock capacities above 100,000 tonnes per year. Current experience with the addition of wastes contaminated with POPs to the feedstock involves much smaller quantities but the capability for treating larger quantities may well exist and is being explored.
284. *Other practical issues:* None

285. *State of commercialization:* Cast iron production from iron-containing materials of iron and steel production in a conventional blast furnace has been in operation for some years in Germany (www.dk-duisburg.de). A shaft furnace (“Oxycup furnace”) has been in operation since 2003 in Germany (www.thyssenkrupp.com). The hearth furnace process has been in operation on an industrial scale in Luxembourg since 2003 (www.paulwurth.com) and in Italy (www.lucchini.it). The Waelz rotary kiln process is well-established and is covered by BAT operating at different sites in Europe (www.bus-steel.com). The vertical bath melting process is operating in Germany (www.na-ag.com) as is the horizontal bath melting process (www.berzelius.de).

286. *Vendors:* As the primary use of plants operating these processes is not the destruction of the POP content in wastes there are no vendors of plants dedicated to this purpose.

(I) Waste-to-gas conversion

287. *Process description:* The process¹⁴⁵ is a gasification pre-treatment and treatment technology for the recovery of hydrocarbon-containing waste operating at high temperatures (1300°C–2000°C) and high pressure (about 25 bar) using steam and pure oxygen in a reducing atmosphere¹⁴⁶. All hydrocarbon molecules in the waste are irreversibly cleft into small gaseous molecules such as hydrogen (H₂) and carbon monoxide (CO), methane (CH₄) and carbon dioxide (CO₂). Short-chain hydrocarbons such as ethane (C₂H₆), propane (C₃H₈) and butane (C₄H₁₀) and other compounds are produced in small amounts (< 1 vol. %). Persistent organic pollutants including PCBs contained in the waste are effectively destroyed. The resulting raw gas is subsequently converted in a multistage process to pure synthesis gas for the production of highest-grade methanol.

288. *Efficiency:* DEs of 99.974 per cent have been reported for PCDDs and PCDFs¹⁴⁷.

289. *Waste types:* The process is suitable for a large variety of organic waste in different physical forms, i.e., solids, liquids, sludge and slurry containing or contaminated with POPs. Wastes containing or contaminated with PCBs (up to 500 mg/kg waste) and PCDDs/PCDFs (up to 50.000 ng TEQ/kg) may be treated. The chlorine levels in the hazardous waste can reach up to 6 wt. % (fluids) and 10 wt. % (solids).

290. *Pre-treatment:* Step (a): size reduction is required for solid waste with pieces extending 80 x 140 mm. Solid waste with pieces not extending 80 x 140 mm directly undergoes step (b). Ferrous and non ferrous metals are removed from solid wastes. After pelletizing, the waste undergoes step (b). In the case of liquid and pasty waste, sludge, solids and water are separated by sedimentation and density separation. The pre-purified oil is distilled in order to reach water content of < 1%. There is no water content restriction for slurry products to be fed into the entrained flow gasifier. Step (b): Gasification of waste (including drying and degassing) generates raw gas for further processing.

291. *Emissions and residues:* Sulphur and nitrogen compounds contained in the raw gas are removed in the gas processing facilities emission-free, in a sealed pressure system. Traces of POPs (0.0034 ng TEQ/Nm³)¹⁴⁸ in the raw gas are finally destroyed in the entrained-flow gasifier at temperatures of 2000°C. PCBs, PCDDs and PCDFs have not been detected by analytic means in the methanol produced and in water, slag and gypsum. The vitrified slag may contain heavy metal compounds; that slag is capable of being recycled e.g., into insulating materials. Since the waste-to-gas conversion process takes place in a reducing atmosphere the possibility of the formation of PCDDs and PCDFs is limited. PCDDs and PCDFs emissions to air are reported as follows: Desulfurization plant 0.0006 ng TEQ/Nm³; boiler plant 0.0029 ng TEQ/Nm³.¹⁴⁹

292. *Release control and post-treatment:* CO₂ and other gases are removed already from the raw gas in separate fractions using an organic adsorbent (methanol) at subzero temperatures. Flammable gases are burned in a boiler plant; high quality steam is generated from this process.

293. *Energy requirements:* The waste is treated with a gasification mixture containing at least 15 wt. % coals in order to ensure stable process conditions. No additional energy in the form of electricity or steam is necessary.

¹⁴⁵ B. Buttker et al., 2005 in annex V, Bibliography

¹⁴⁶ Three types of gasifiers are operated by SVZ: pressurized bed gasifier, slagging gasifier BGL, entrained flow gasifier.

¹⁴⁷ Reported DE mainly depends on low PCDD/F-concentration of 34.08 ng TEQ/kg in treated waste. DE is 99.99143 when PCDD/F-concentration in waste reaches 50.000 ng TEQ/kg. See B. Buttker et al., 2006.

¹⁴⁸ B. Buttker et. al., 2006 in annex V, Bibliography

¹⁴⁹ Ibid.

294. *Material requirements:* There is a need for a gasification agent (steam and oxygen) for the gasification technologies used. Other material requirements include calcium carbonate (limestone) to influence viscosity of slag.

295. *Portability:* The gasification technology is available only in fixed configurations.

296. *Health and safety:* The process effectively destroys POPs in a closed loop system without endangering human health or the environment. Use of hydrogen gas under pressure requires suitable controls and safeguards to ensure that explosive air-hydrogen mixtures are not formed. Operating experience gained from 1992 to date has indicated that the process can be undertaken safely.

297. *Capacity:* Per year about 300,000 tonnes of solid and about 60,000 tonnes of liquid and pasty wastes can be treated.

298. *Other practical issues:* As large quantities are handled, appropriate and environmentally compatible storage capacities are required.

299. *State of commercialization:* Commercial scale waste gasification is operated in Germany since 1992 in the Sekundärrohstoff-Verwertungszentrum Schwarze Pumpe (SVZ). More than 2.5 million tonnes of waste have been treated within the last ten years.

300. *Vendors:* Sustec Holding holds the patent for the entrained flow gasifier technology. Sustec sells licences to operate the technology. Licenses to operate the slagging gasifier technology are sold by Sustec Schwarze Pumpe Inc. together with Envirotherm Inc (www.svz-gmbh.de/).

3. Other disposal methods when neither destruction nor irreversible transformation is the environmentally preferable option

301. Where neither destruction nor irreversible transformation is the environmentally preferable option, for wastes with a POP content above the low POP content referred to in subsection A of section III above countries may allow such wastes to be disposed of by other methods than the methods referred to in subsection IV.G.2.

302. Wastes containing or contaminated with POPs where such other disposal methods may be considered include:

(a) Waste from power stations and other combustion plants (except those listed in subparagraph (d) below), wastes from the iron and steel industry and wastes from aluminium, lead, zinc, copper and other non-ferrous thermal metallurgy. These include bottom ash, slag, salt slags, fly ash, boiler dust, flue-gas dust, other particulates and dust, solid wastes from gas treatment, black drosses, wastes from treatment of salt slags and black drosses, dross and skimmings;

(b) Carbon-based and other linings and refractories from metallurgical processes;

(c) The following construction and demolition wastes:

(i) Mixtures of, or separate fractions of, concrete, bricks, tiles and ceramics;

(ii) The inorganic fraction of soil and stones, including excavated soil from contaminated sites;

(iii) Construction and demolition wastes containing PCBs, excluding equipment containing PCBs;

(d) Wastes from the incineration or pyrolysis of waste, including solid wastes from gas treatment, bottom ash, slag, fly ash and boiler dust;

(e) Vitriified wastes and waste from vitrification, including fly ash and other flue-gas treatment wastes and non-vitriified solid phase wastes.

303. The relevant authority of the country concerned should be satisfied that neither destruction nor irreversible transformation of the POP content, performed according to best environmental practice or best available techniques, is the environmentally preferable option.

304. Other disposal methods when neither destruction nor irreversible transformation is the environmentally preferable option include those described below.

(a) Specially engineered landfill¹⁵⁰

305. Any landfilling should be carried out in a way that minimizes the potential of the POPs content to enter the environment. This may be achieved by pre-treatment, e.g., a suitable solidification process. A specially engineered landfill should comply with requirements as regards location, conditioning, management, control, closure and preventive and protective measures to be taken against any threat to the environment in the short- as well as in the long-term perspective, in particular as regards measures against the pollution of groundwater by leachate infiltration into the soil. Protection of soil, groundwater and surface water should be achieved by the combination of a geological barrier and a bottom liner system during the operational phase and by the combination of a geological barrier and a top liner during the closure and post-closure phase. Measures should also be taken to reduce the production of methane gas and to introduce landfill gas control. In addition, a uniform waste acceptance procedure on the basis of a classification procedure for waste acceptable in the landfill, including in particular standardized limit values, should be introduced. Moreover, monitoring procedures during the operation and post-closure phases of a landfill should be established in order to identify any possible adverse environmental effects of the landfill and take the appropriate corrective measures. A specific permit procedure should be introduced for the landfill. Permits should include specifications regarding types and concentrations of wastes to be accepted, leachate and gas control systems, monitoring, on-site security, and closure and post-closure.

306. The following wastes containing or contaminated with POPs are not suitable for disposal in specially engineered landfills:

- (a) Liquids and materials containing free liquids;
- (b) Biodegradable organic wastes;
- (c) Empty containers, unless they are crushed, shredded or similarly reduced in volume;
- (d) Explosives, flammable solids, spontaneously combustible materials, water-reactive materials, oxidizers and organic peroxides.

(b) Permanent storage in underground mines and formations

307. Permanent storage in facilities located underground in geohydrologically isolated salt mines and hard rock formations is an option to separate hazardous wastes from the biosphere for geological periods of time. A site-specific security assessment according to pertinent national legislation such as the provisions contained in appendix A to the annex to European Council decision 2003/33/EC of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to article 16 of and annex II to directive 1999/31/EC should be performed for every planned underground storage facility.

308. Wastes should be disposed of in a manner that excludes any undesirable reaction between different wastes or between wastes and the storage lining, among other things by storing in chemically and mechanically secure containers. Wastes that are liquid, gaseous, emit toxic gases or are explosive, flammable or infectious should not be stored underground in mines. Operational permits should define waste types that should be generally excluded.

309. The following should be considered in the selection of permanent storage for disposal of wastes consisting of, containing or contaminated with POPs:

- (a) Caverns or tunnels used for storage should be completely separated from active mining areas and areas that maybe reopened for mining;
- (b) Caverns or tunnels should be located in geological formations that are well below zones of available groundwater or in formations that are completely isolated by impermeable rock or clay layers from water-bearing zones;
- (c) Caverns and tunnels should be located in geological formations that are extremely stable and not in areas subject to earthquakes.

¹⁵⁰ Further information is available within Technical Guidelines on Specially Engineered Landfill (D5), UNEP, 1995d, in annex V, Bibliography, and pertinent national legislation such as the European Directive 1999/31/EC.

4. Other disposal methods when the POP content is low

310. If wastes containing or contaminated with POPs at concentrations under the low POP content are not disposed of with the methods described above, they should be disposed of in accordance with pertinent national legislation and international rules, standards and guidelines, including the specific technical guidelines developed under the Basel Convention. Examples of pertinent national legislation are given in annex II to the present guidelines.

H. Remediation of contaminated sites

1. Contaminated site identification¹⁵¹

311. Poor handling and storage practices in particular may lead to releases of POPs at sites storing these chemicals, resulting in contamination of the site with high levels of POPs that may pose serious health concerns. Identification of such sites is the first step in addressing potential concerns.

312. Identification of such sites can be undertaken using a phased approach, including:

- (a) Identification of suspect sites, such as sites involved in:
 - (i) Manufacture of POPs;
 - (ii) Formulation of pesticides and filling and refilling of transformers;
 - (iii) Usage of POPs, such as, application of pesticides and placement of transformers;
 - (iv) Disposal of wastes consisting of, containing or contaminated with POPs;
- (b) Review of current and historical information pertaining to the suspected site;
- (c) An initial testing programme to confirm the presence or absence of suspected contaminants and characterize the physical conditions at the suspected site;
- (d) A detailed testing programme to identify the nature of the site contamination and gather any additional information required.

2. Environmentally sound remediation¹⁵²

313. Contaminated site criteria developed by governments using risk assessment techniques are used as general targets in site remediation. Separate criteria can be developed or adopted for soil, sediment and groundwater. Often, a distinction is made between industrial (least stringent criteria), commercial, residential and agricultural (most stringent criteria) soils. Examples of such criteria can be found in the German federal soil protection and contaminated sites ordinance, the Swiss soil burden ordinance and the Canadian environmental quality guidelines.¹⁵³

I. Health and safety¹⁵⁴

314. In general, there are three main ways to protect workers and members of the public from chemical hazards (in order of preference):

- (a) Keep workers and members of the public away from all possible sources of contamination;
- (b) Control the contaminants so that the possibility of exposure is minimized;
- (c) Protect workers by ensuring that personal protective equipment is used.

¹⁵¹ Further information on contaminated site identification is available within *Assessing Soil Contamination: A Reference Manual No. 8* (FAO, 2000) and *Guidance Document on the Management of Contaminated Sites in Canada* (Canadian Council of Ministers of the Environment, 1997). See annex V, Bibliography.

¹⁵² Information on methods currently used for the remediation of sites contaminated with POPs is available from a variety of sources including FRTR (2002), United States Environmental Protection Agency (1993 and 2000) and Vijgen (2002). See annex V, Bibliography.

¹⁵³ See Canadian Council of Ministers of the Environment, 2002 in annex V, Bibliography.

¹⁵⁴ Further information on health and safety is also available from the International Labour Organization (1999a and 1999b), the World Health Organization (1995 and 1999) and IPCS INCHEM (no date). See annex V, Bibliography.

315. Information on health and safety is also available from ILO (1999a and 1999b), WHO (1995 and 1999), IPCS INCHEM (various dates) and United Kingdom Health and Safety Executive guidance note HS(G)66 "Protection of workers and the general public during the development of contaminated land". Examples of practical implementation can be found in UNEP 2001.

316. Health and safety plans should be in place at all facilities that handle wastes consisting of, containing or contaminated with POPs to ensure the protection of everyone in and around the facility. The health and safety plan for each specific facility should be developed by a trained health and safety professional with experience in managing the health risks associated with the specific POPs at the facility.

317. All health and safety plans should adhere to the above principles and recognize local or national labour standards. Most health and safety programmes recognize various levels of safety, with risk levels depending on the site in question and the nature of the contaminated materials found there. The level of protection provided to workers should correspond to the level of the risk to which they are exposed. Levels of risk should be established and each situation should be evaluated by health and safety professionals. Two situations are discussed below: higher-risk and lower-risk.

1. Higher-risk situations

318. Higher-risk situations occur where high concentrations of POPs or high volumes of wastes consisting of, containing or contaminated with POPs are found and a high potential for exposure is present. Such situations may potentially expose workers and the general population. Particular efforts should be made to minimize public exposure. In addition, guidance should be provided to ensure that the public is aware of the potential risk and of the measures to be taken in cases of exposure.

319. There is no international, quantitative definition of high volume or high concentration. Workers and employers can be guided by the advice and input of health and safety professionals, labour representatives, the scientific literature and government authorities. Potential higher-risk situations may occur:

- (a) At sites producing, handling, and using POPs;
- (b) At stockpiles of and large-volume storage sites for chemicals or wastes consisting of, containing or contaminated with POPs;
- (c) At facilities for the treatment or disposal of wastes consisting of, containing or contaminated with POPs;
- (d) At sites contaminated with high concentrations of POPs at or near the surface.

320. At a minimum, POPs health and safety planning for higher-risk situations should include the following elements:

- (a) A written health and safety plan (HASP) should be developed and posted at each site;
- (b) Workers who are to have access to the site should read the HASP and sign to confirm that they have read and understood it;
- (c) The HASP may be written to encompass all hazards at the site but should have a section or chapter specifically detailing procedures for POPs;
- (d) Workers should be present at the site only when necessary for servicing or inspecting equipment or stored materials;
- (e) Workers entering the site should have appropriate health and safety and operational training for chemical, physical and biological hazards;
- (f) Health and safety training should be performed annually;
- (g) Routine air monitoring should be carried out to detect the presence of POP contaminants;
- (h) When appropriate, workers entering the site should wear appropriate respiratory protection, and impermeable fabric should cover the entire body (i.e., coveralls with hood, face shield, gloves and boot covers or a full body suit);
- (i) Spill clean-up kits and personal decontamination materials should be present in all areas containing POPs;
- (j) Workers who are or are expected to be routinely entering sites or working with POP substances should undergo medical monitoring, including a baseline medical examination;

(k) Where POPs are to be handled in an open system or where it is reasonably expected that the protective clothing of a worker may be contaminated with POPs, a contaminant reduction zone should be established where workers can be decontaminated and remove their protective equipment;

(l) The HASP and general work procedures should be reviewed at least annually and revised if necessary to enhance health and safety at the site.

2. Lower-risk situations

321. There is also no definition of low volume or low concentration. These should be determined by comparing contaminant levels with government guidelines or by conducting site-specific risk assessments. Lower-risk situations may include:

(a) Sites that contain materials contaminated with POPs in small quantities or at low concentrations;

(b) Controlled storage rooms that contain small quantities of POPs;

(c) Sites contaminated with low concentrations of POPs or where the contamination cannot come directly into contact with people.

322. Despite the low risk, some health and safety measures should be taken to minimize exposure, including health and safety training of personnel who are likely to come into contact with POPs.

J. Emergency response¹⁵⁵

323. Emergency response plans should be in place for all POPs in production, in use, in storage, in transport or at disposal sites. While the emergency response plans can vary for each situation and each type of POP, the principal elements of an emergency response include:

(a) Identifying all potential hazards, risks and accident events;

(b) Identifying relevant local and national legislation governing emergency response plans;

(c) Planning for anticipated emergency situations and possible responses;

(d) Maintaining a complete up-to-date inventory of all POPs on site;

(e) Training personnel in response activities, including simulated response exercises and first aid;

(f) Maintaining mobile spill response capabilities or retaining the services of a specialized firm for spill response;

(g) Notifying fire services, police and other government emergency response agencies of the location of POPs and the routes of transport;

(h) Installing mitigation measures such as fire suppression systems, spill containment equipment, fire-fighting water containment, spill and fire alarms and firewalls;

(i) Installing emergency communication systems including signs indicating emergency exits, telephone numbers, alarm locations and response instructions;

(j) Installing and maintaining emergency response kits containing sorbents, personal protective equipment, portable fire extinguishers and first aid supplies;

(k) Integrating facility plans with local, regional, national and global emergency plans, if appropriate;

(l) Regular testing of emergency response equipment and review of emergency response plans.

324. Emergency response plans should be prepared jointly by interdisciplinary teams that include emergency response, medical, chemical and technical personnel and also representatives of labour and management. When applicable, representatives of potentially impacted communities should also be included.

¹⁵⁵ Further guidance on emergency response plans can be found in other guidelines developed by international organizations, such as the OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response, second edition (2003) and by national, regional or local governments or agencies (such as civil defence and emergency coordination agencies and fire departments).

K. Public participation

325. Public participation is a core principle of the Basel Declaration on Environmentally Sound Management and many other international agreements. It is essential that the public and all stakeholder groups have a chance to participate in the development of policy related to POPs, planning of programmes, development of legislation, review of documents and data, and decision-making on local issues related to POPs. Paragraphs 6 (g) and (h) of the Basel Declaration address the enhancement of information exchange, education and awareness-raising in all sectors of society and cooperation and partnership between countries, public authorities, international organizations, industry, non-governmental organizations and academic institutions.

326. The Stockholm Convention, in its article 10, paragraph 1 (d), calls on each Party, within its capabilities, to promote and facilitate public participation in addressing POPs and their health and environmental effects and in developing adequate responses, including opportunities for providing input at the national level regarding implementation of this Convention.

327. Articles 6, 7, 8, and 9 of the 1998 Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters require the conduct of fairly specific types of activities regarding public participation in specific government activities, the development of plans, policies and programmes, and the development of legislation, and call for access to justice for the public with regard to the environment.

328. The participation of the public in the establishment of standards and regulations for POPs is essential. Any Government planning new or changed regulations or policies should have an open process for soliciting comment from any and all persons or groups. This means that a general invitation to comment is given through regular media outlets, the internet, or by direct invitation. The individuals and groups who should be considered for direct invitation to comment are:

- (a) Individual citizens who have expressed interest;
- (b) Local citizens' groups, including local environmental groups, for local issues;
- (c) Groups of highly vulnerable people, such as women, children and the least educated;
- (d) Regionally, nationally or globally organized environmental groups;
- (e) Individual industries and businesses with a stake in the process;
- (f) Business associations;
- (g) Trade unions and associations;
- (h) Professional associations;
- (i) Other levels of government.

329. A public participation process may have several phases. Groups may be consulted before any changes or programmes are considered, during the policy development process and after each draft policy document is prepared. Comments may be invited in person, in writing or through an internet website.

330. An example of public consultation regarding the development of POPs management plans can be found in the Australia Department of the Environment and Heritage document, "A case study of problem solving through effective community consultation"¹⁵⁶.

¹⁵⁶

See Australia Department of the Environment and Heritage, 2000 in annex V, Bibliography.

Annex I

International instruments

In addition to the Stockholm and Basel conventions, there are other international instruments that contain provisions pertaining to wastes containing, consisting of or contaminated with POPs , including:

- (a) 1998 Protocol on Persistent Organic Pollutants to the 1979 Convention on Long-range Transboundary Air Pollution;
- (b) 2003 Protocol on Pollutant Release and Transfer Registers to the 1998 Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters;
- (c) 1991 Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa;
- (d) Waigani Convention to Ban the Importation into Forum Island Countries of Hazardous and Radioactive Wastes and to Control the Transboundary Movement and Management of Hazardous Wastes within the South Pacific Region; and
- (e) OECD Council decision C (2001) 107/FINAL Concerning the Control of Transboundary Movements of Wastes Destined for Recovery Operations.

Annex II

Examples of pertinent national legislation

Examples of national legislation containing provisions related to the management of wastes consisting of, containing or contaminated with POPs include those outlined below.

Country	Legislation	Brief description
Austria	Soil Protection Acts	<ul style="list-style-type: none"> Contains stringent limit values on PCBs, PCDDs and PCDFs in sewage sludge used as fertilizer.
Brazil	Norm ABNT/NBR, N° 8371/1997	<ul style="list-style-type: none"> Procedures for handling, transport and storage of materials containing PCBs
Brazil	Resolution CETESB (São Paulo state), N° 007/1997	<ul style="list-style-type: none"> Determines limits for PCDDs and PCDFs on emissions from medical waste incinerators with capacity > 200 kg/day
Brazil	Resolution CONAMA, N° 264/1999	<ul style="list-style-type: none"> Procedures for environmental licensing on waste co-processing in cement kilns
Brazil	Resolution CONAMA, N° 313/2002	<ul style="list-style-type: none"> Provides for an inventory of PCB stocks and industrial wastes
Brazil	Resolution CONAMA, N° 316/2002	<ul style="list-style-type: none"> Procedures and criteria for operating thermal wastes treatment systems, provides limits on emissions of PCDDs and PCDFs
Brazil	Resolution CONAMA, N° 334/2003	<ul style="list-style-type: none"> Procedures for environmental licensing for those establishments responsible for receiving pesticides package
Brazil	Decision CETESB (São Paulo state), N° 26/2003	<ul style="list-style-type: none"> Sets limits for air emissions of PCDDs and PCDFs of cement kilns treating also waste
Brazil	Resolution CONAMA, N° 357/2005	<ul style="list-style-type: none"> Provides maximum permitted levels for POPs in effluents discharged to water
Canada	Federal Mobile PCB Treatment and Destruction Regulations	<ul style="list-style-type: none"> Contains emission standards for release of gases, liquids and solids contaminated with PCBs, PCDDs and PCDFs.
European Community	Regulation (EC) No 850/2004 of the European Parliament and of the Council of 29 April 2004 on persistent organic pollutants and amending Directive 79/117/EEC, amended by Council Regulation (EC) No. 1195/2006 of 18 July 2006 amending Annex IV to Regulation (EC) No. 850/2004	<ul style="list-style-type: none"> Article 7 contains provisions regarding the management of wastes containing, consisting of or contaminated with POPs.
European Community	Council Directive 96/59/EC of 16 September 1996 on the disposal of polychlorinated biphenyls and polychlorinated terphenyls (PCB/PCT)	<ul style="list-style-type: none"> Contains regarding the disposal of PCBs and PCTs, inter alia on the decontamination and/or disposal of equipment and the PCBs therein.
European Community	86/280/EEC Council Directive of June 12 1986 on limit values and quality objectives for discharges of certain dangerous substances included in List I of the Annex to Directive 76/464/EEC and 88/347/EEC Council Directive of June 16 1988 amending Annex II to Directive 86/280/EEC on limit values and quality objectives for discharges of certain dangerous substances included in List I of the Annex to Directive 76/464/EEC	<ul style="list-style-type: none"> Annex II contains emission limit values for discharge of aldrin, dieldrin, endrin and HCB-contaminated waste water produced during production.
European Community	Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste	<ul style="list-style-type: none"> Annex IV contains emission limit values for discharges of PCDD and PCDF contaminated waste water from the cleaning of exhaust gases. Annex V contains air emission values for PCDDs and PCDFs

Country	Legislation	Brief description
European Community	Council Decision 2003/33/EC of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC	<ul style="list-style-type: none"> Paragraph 2.1.2.2 of the Annex contains criteria for landfill of inert waste containing PCBs.
Finland	Council of State decision (1071/1989) on the restriction of the use of PCBs and PCTs	<ul style="list-style-type: none"> Contains limit values for PCBs and PCTs
Finland	Council of State decision (101/1997) on oil waste management	<ul style="list-style-type: none"> Contains limit values for PCBs in regenerated oil and in oil wastes destined for incineration
Finland	Council of State decision (711/1998) on the disuse of PCB appliances and the treatment of PCB waste	<ul style="list-style-type: none"> Contains limit values for PCBs
Finland	Council of State decree (1129/2001) on a list of the most general wastes and hazardous wastes	<ul style="list-style-type: none"> Contains limit values for PCBs
Germany	Federal Soil Protection and Contaminated Sites Ordinance	<ul style="list-style-type: none"> Contains action levels regarding sites contaminated with aldrin, DDT, HCB, PCBs, PCDDs and PCDFs.
Germany	Ordinance on Landfills and Long-Term Storage Facilities	<ul style="list-style-type: none"> Contains a limit for PCBs in soils used as recultivation layers of landfills. Prohibits the landfilling of waste, which may harm public welfare due to its content of long-lived or bio-accumulable toxic substances.
Germany	Ordinance on Underground Waste Stowage	<ul style="list-style-type: none"> Contains limits for use of waste contaminated with PCBs as stowage material.
Germany	Sewage Sludge Ordinance	<ul style="list-style-type: none"> Contains limits for usage of sewage sludge contaminated with PCBs, PCDDs and PCDFs as fertilizer.
Germany	Waste Wood Ordinance	<ul style="list-style-type: none"> Contains limits for recycling of waste wood contaminated with PCBs.
Germany	Waste Oil Ordinance	<ul style="list-style-type: none"> Contains limits for recycling of PCB contaminated oils.
Japan	Law Concerning Special Measures Against Dioxins	<ul style="list-style-type: none"> Contains tolerable daily intake environmental standards for ambient air, water quality (including sediment) and soil, emission and residue standards for gas, effluent, ash and dust regarding PCDDs, PCDFs and co-planar PCBs.
Japan	Law Concerning Special Measures Against PCB Wastes	<ul style="list-style-type: none"> Contains standards for the treatment of plastics and metals contaminated with PCBs.
Japan	Law Concerning Special Measures Against Soil Contamination	<ul style="list-style-type: none"> Contains standards for the treatment of soil contaminated with PCBs.
Japan	Waste Management and Public Cleansing Law	<ul style="list-style-type: none"> Contains criteria of hazardous wastes containing PCBs, PCDDs, PCDFs and co-planar PCBs.
Japan	Water Pollution Control Law	<ul style="list-style-type: none"> Contains emission standards for effluent containing PCBs.
Mexico	Norm NOM-098 of 2004	<ul style="list-style-type: none"> Contains emission and destruction efficiency standards for waste incinerators.
Mexico	Norm NOM-133 of 2001	<ul style="list-style-type: none"> Contains regulations regarding handling of PCBs and a programme for the preparation of inventories.
Norway	Norwegian Product Regulation chapters 2 and 3 on regulated hazardous substances or a mix of substances and products containing hazardous substances	<ul style="list-style-type: none"> Contains a ban on the production, use, import and export of PCBs, PCTs and products containing these substances, including PCB-containing capacitors.
Norway	Norwegian Waste Regulation chapter 14 on obsolete insulation windows that contain PCB	<ul style="list-style-type: none"> Lays down requirements for the producers to collect and handle obsolete windows that contain PCBs.

Country	Legislation	Brief description
Norway	Norwegian Pollution Regulation chapter 2 on clean-up of contaminated sites	<ul style="list-style-type: none"> Contains limit values below which a soil is considered to be clean and suitable for use in sensitive areas.
Switzerland	Soil Burden Ordinance	<ul style="list-style-type: none"> Contains actions levels regarding sites contaminated with PCBs, PCDDs and PCDFs.
United States of America	EPA 40 CFR 63 Subpart EEE National Emission Standards for Hazardous Air Pollutants from Hazardous Waste Combustors	<ul style="list-style-type: none"> Contains standards for releases of PCDDs and PCDFs within air emissions.
United States of America	40 CFR 268.48 Universal Treatment Standards for Hazardous Wastes	<ul style="list-style-type: none"> Contains standards for the treatment of hazardous waste prior to land disposal and aqueous waste prior to release. Covers all POPs except mirex.
United States of America	40 CFR 761.70 Standards for incineration of PCBs	<ul style="list-style-type: none"> Contains standards for air emissions, when incinerating PCBs

Annex III

Selected analytical methods for POPs

1. Aldrin

- (a) AOAC Official Method 970.52 Organochlorine and Organophosphorous Pesticide Residue Method. General Multiresidue Method. 2005 AOAC International
- (b) AOAC Official Method 955.22 Organochlorine and Organophosphorous Pesticide Residue Method
- (c) EPA Method 8081A: Organochlorine Pesticides by Gas Chromatography (and ECD)
- (d) ISO 6468 (1996) Water quality – Determination of certain organochlorine insecticides, polychlorinated biphenyls and chlorobenzenes – Gas chromatographic method after liquid-liquid extraction
- (e) ISO 10382 (2002): Soil quality – Determination of organochlorine pesticides and polychlorinated biphenyls – Gas-chromatographic method with electron capture detection

2. DDT

- (a) AOAC Official Method 970.52 Organochlorine and Organophosphorous Pesticide Residue Method. General Multiresidue Method. 2005 AOAC International
- (b) AOAC Official Method 955.22 Organochlorine and Organophosphorous Pesticide Residue Method
- (c) EPA Method 4042: Soil screening for DDT by immunoassay, EPA analytical chemistry guidance SW-846
- (d) EPA Method 8081A: Organochlorine Pesticides by Gas Chromatography (and ECD)
- (e) ISO 6468 (1996) Water quality – Determination of certain organochlorine insecticides, polychlorinated biphenyls and chlorobenzenes – Gas chromatographic method after liquid-liquid extraction
- (f) ISO 10382 (2002): Soil quality – Determination of organochlorine pesticides and polychlorinated biphenyls – Gas-chromatographic method with electron capture detection

3. HCB

- (a) AOAC Official Method 970.52 Organochlorine and Organophosphorous Pesticide Residue Method. General Multiresidue Method. 2005 AOAC International
- (b) AOAC Official Method 955.22 Organochlorine and Organophosphorous Pesticide Residue Method
- (c) EPA Method 8081A: Organochlorine Pesticides by Gas Chromatography (and ECD)
- (d) ISO 6468 (1996) Water quality – Determination of certain organochlorine insecticides, polychlorinated biphenyls and chlorobenzenes – Gas chromatographic method after liquid-liquid extraction
- (e) ISO 10382 (2002): Soil quality – Determination of organochlorine pesticides and polychlorinated biphenyls – Gas-chromatographic method with electron capture detection

4. PCBs

- (a) DIN 38414-20 (1996): German standard methods for the examination of water, waste water and sludge - Sludge and sediments (group S) - Part 20: Determination of 6 polychlorinated biphenyls (PCB) (P 20)
- (b) EN 1948 (draft 2004) Stationary source emissions – determination of the mass concentration of PCDDs/PCDFs and dioxin-like PCBs. Part 1 Sampling, Part 2: Extraction and clean-up of PCDDs/PCDFs, Part 3: Identification and quantification of PCDDs/PCDFs

- (c) EN 12766-1 (2000): Petroleum products and used oils – Determination of PCBs and related products – Part 1: Separation and determination of selected PCB congeners by gas chromatography (GC) using an electron capture detector (ECD)
- (d) EN 12766-2 (2001): Petroleum products and used oils – Determination of PCBs and related products – Part 2: Calculation of polychlorinated biphenyl (PCB) content
- (e) EN 61619 (2004): Insulating liquids – Contamination by polychlorinated biphenyls (PCBs) – Method of determination by capillary column gas chromatography
- (f) EPA Method 1668, Revision A: Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by HRGC/HRMS, United States Office of Water, EPA No. EPA 821-R-00-002, Environmental Protection Agency (4303), December 1999
- (g) EPA Method 4020: Screening for polychlorinated biphenyls by immunoassay (www.epa.gov/epaoswer/hazwaste/test/pdfs/4020.pdf)
- (h) EPA Method 8080: Organochlorine Pesticides and PCBs
- (i) EPA Method 8082: Polychlorinated biphenyls (PCBs) by gas chromatography (www.epa.gov/epaoswer/hazwaste/test/pdfs/8082.pdf)
- (j) EPA Method 8275A: Semivolatile organic compounds (PAHs and PCBs) in soils/sludges and solid wastes using thermal extraction/gas chromatography/mass spectrometry (TE/GC/MS), EPA analytical chemistry guidance SW-846
- (k) EPA Method 9078: Screening test method for polychlorinated biphenyls in soil (www.epa.gov/epaoswer/hazwaste/test/pdfs/9078.pdf)
- (l) EPA Method 9079: Screening test method for polychlorinated biphenyls in transformer oil (www.epa.gov/epaoswer/hazwaste/test/pdfs/9079.pdf)
- (m) ISO 6468 (1996) Water quality – Determination of certain organochlorine insecticides, polychlorinated biphenyls and chlorobenzenes – Gas chromatographic method after liquid-liquid extraction
- (n) ISO 10382 (2002): Soil quality – Determination of organochlorine pesticides and polychlorinated biphenyls – Gas-chromatographic method with electron capture detection
- (o) JIS K 0093 (2002): Testing method for polychlorobiphenyl in industrial water and wastewater
- (p) Methods for Examining Standards of General Wastes under Special Control and Industrial Waste under Special Control, Notice 192 of the Japan Ministry of Welfare and Labour, 3 July 1992
- (q) NEN 7374 (2004): Leaching characteristics – Column test for the determination of the leaching of PAH, PCB, OCP and EOX, phenol and cresoles from granular materials - Solid earthy and stony materials
- (r) Norm NBR N° 13882:1997: Electrical Insulating Liquids - Determination of PCB contents
- (s) Norwegian Institute for Water Research method no. H 3-2: Determination of organochlorine compounds in sediments, water and biological material by gas chromatography
- (t) NVN 7350 (1997): Leaching characteristics of solid earthy and stony building and waste materials – Leaching tests – Determination of the leaching of PAH, PCB and EOX from granular materials with the cascade test
- (u) NVN 7376 (2004): Leaching characteristics – determination of the leaching of PAH, PCB, OCP and EOX, phenol and cresoles from building and monolithic waste materials with diffusion test – Solid earthy and stony materials

5. PCDDs and PCDFs

- (a) EN 1948 (draft 2006): Stationary source emissions – determination of the mass concentration of PCDDs/PCDFs and dioxin-like PCBs. Part 1 Sampling, Part 2: Extraction and clean-up of PCDDs/PCDFs, Part 3: Identification and quantification of PCDDs/PCDFs, Part 4: Sampling and analysis of dioxin-like PCBs
- (b) EN 1948 (1997): Stationary source emissions – determination of the mass concentration of PCDDs/PCDFs. Part 1 Sampling, Part 2: Extraction and clean-up, Part 3: Identification and quantification
- (c) EPA Method 1613: Tetra-through Octa-Chlorinated Dioxins and Furans by Isotope Dilution HRGC/HRMS, October 1994, (www.epa.gov/waterscience/methods/1613.pdf)
- (d) EPA Method 0023A: Sampling Method for Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofuran Emissions from Stationary Sources. Revision 1 December 1996 (www.epa.gov/SW-846/pdfs/0023a.pdf)
- (e) EPA Method 8290A: Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by High-Resolution Gas Chromatography/High-Resolution Mass Spectrometry (HRGC/HRMS), revision 1 January 1998
- (f) EPA Method T09: Determination of polychlorinated dibenzo-p-dioxins (PCDDs) in ambient air using high-resolution mass spectrometry (HRGC/HRMS)
- (g) EPA Method 8280A: The analysis of polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans by high resolution gas chromatography/low resolution mass spectrometry (HRGC/LRMS) (EPA analytical chemistry guidance SW-846)
- (h) EPA Method 8290: Polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) by high-resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS) (EPA analytical chemistry guidance SW-846)
- (i) EPS (1990): A Method for the Analysis of Polychlorinated Dibenzo-*para*-Dioxins (PCDDs), Polychlorinated Dibenzofurans (PCDFs) and Polychlorinated Biphenyls (PCBs) in Samples from the Incineration of PCB Waste. Reference Method 1/RM/2 and Reference Method 1/RM/3 (revised) May 1990
- (j) ISO 18073 (2004): Water quality – Determination of tetra- to octa-chlorinated dioxins and furans – Method using isotope dilution HRGC/HRMS
- (k) JIS K 0311 (1999): Method for determination of tetra- through octa-chlorodibenzo-*p*-dioxins, tetra- through octa-chlorodibenzofurans and coplanar polychlorobiphenyls in stationary source emissions
- (l) JIS K 0312 (1999): Method for determination of tetra- through octa-chlorodibenzo-*p*-dioxins, tetra- through octa-chlorodibenzofurans and coplanar polychlorobiphenyls in industrial water and waste water
- (m) Methods for Examining Standards of General Wastes under Special Control and Industrial Waste under Special Control (Notice 192 of the Japan Ministry of Welfare and Labour, July 3, 1992)

6. Solid waste, particulate materials

Nordtest: Method NT ENVIR 004; Solid Waste, Particulate Materials: Sampling, ISSN 1238-4445, 1996

Annex IV

Economics of destruction and irreversible transformation methods

It should be noted that the information in table 1 and 2 below is intended only to provide a broad reference based on available cost estimates of the various destruction and irreversible transformation methods discussed in the present guidelines.

This information is not representative as several factors influence the data, such as the scarcity of data, the various points of time the data were estimated, the different currencies, the varying currency exchange rates, local costs of electricity, labour and materials, and also the quantity of waste involved and the use made of the technology (theoretically, the cost of technology should get cheaper over time).

Further information will be available in “Inventory of Worldwide PCB Destruction Capacity”. The second issue is expected to be available in the near future.

Table 1: Cost estimates of destruction and irreversible transformation methods

Destruction and irreversible transformation methods	Cost estimates	Source
Alkali metal reduction¹	i. Transformer oils: US\$0.15/L, £500–1000/t, CAN\$4/gallon, CAN\$0.90/kg; and ii. Waste oils: CAN\$0.60/kg.	Vendors UNEP 2004b
Base-catalysed decomposition (BCD)¹	i. Licence fees vary; ii. Operating royalties: 5 per cent – 10 per cent of gross revenues/sales; iii. Capital costs (2,500-gallon BC liquid reactor): US\$800,000–1.4M; iv. Operating costs: US\$728–1,772 depending on the POP concentration.	Extracted in 2004 from BCD Group Inc.’s website
Catalytic hydrodechlorination (CHD)	No data available	
Cement kiln co-incineration	No data available	
Gas-phase chemical reduction (GPCR)²	i. AU\$4,000–6,000/ton for organochlorine pesticide solids; ii. AU\$4,000–\$8,000/ton for PCBs and organochlorine pesticide liquids; iii. AU\$6,000–11,000/ton for PCB-contaminated capacitors	CMPS&F – Environment Australia 1997
Hazardous-waste incineration	See table 2 below	
Photochemical dechlorination (PCD) and catalytic dechlorination (CD) reaction	Available upon request: i. Licence fees ii. Operating royalties or costs	
Plasma arc	Capital cost ¹ (150 kW Plascon™ unit): US\$1 million, depending upon the configuration. Operating costs: below AU\$3,000 (including labour), typically range from AU\$1,500 to AU\$2,000 per ton. The costs depend upon factors such as: i. Waste feed – molecular structure, weight and concentration; ii. Electricity costs; iii. Argon and oxygen costs; iv. Geographic location and site specific issues; v. Caustic costs; and vi. Required emission limits.	CMPS&F – Environment Australia, 1997; Rahuman et al., 2000; UNEP, 2004b

Destruction and irreversible transformation methods	Cost estimates	Source
Potassium tert-Butoxide (t-BuOK) method	No data available	
Super-critical water oxidation (SCWO) and subcritical water oxidation	Costs: US\$120–140/dry ton ³	CMPS&F – Environment Australia, 1997

¹ It is not clear whether these estimates include potential costs associated with pre-treatment and/or disposal of residues.

² It is not clear whether the above includes costs associated with the pre-treatment of solid wastes.

³ Assuming some pre-treatment has been reported. It is not clear whether this estimate incorporates capital costs or costs associated with the disposal of any residues.

Table 2 : Hazardous-waste incineration (for an incinerator treating 70,000 tons per year)

	Investment costs (millions of euros)	
	2004 ^a	1999 ^b
Construction time	3	6.5
Electrical works	10	20
Infrastructure works	6	12.5
Machine parts	16	32.5
Other components	14	27.5
Planning/approval	3	6
Total investment costs	52	105
	Operational costs (million of euros)	
Administration	0.3	0.5
Capital financing costs	5	10.5
Maintenance	4	4
Operating resources/energy	1.3	2.5
Other	0.3	0.5
Personnel	3	5.5
Waste disposal	0.8	1.5
Total operational costs	14.7	25
<i>Per ton incineration costs (without revenues)</i>	<i>200–300</i>	<i>350</i>

Gate fees at hazardous waste incinerators within Europe have been reported to range between €50 and €1,500 (Source: European Commission 2004).

Notes:

^a Source for figures in first column: European Commission 2004.

^b Source for figures in second column: Mean values of the specific costs of incineration for municipal and hazardous wastes (1999), VDI 3460: Emission Control Thermal treatment of waste, Germany, March 2002

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