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**Conference of the Parties to the Basel Convention
on the Control of Transboundary Movements of
Hazardous Wastes and Their Disposal
Sixteenth meeting**
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Agenda item 4 (b) (i)

**Matters related to the implementation of the
Convention: scientific and technical matters:
technical guidelines**

Technical guidelines

Addendum

General technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants

Note by the Secretariat

At its sixteenth meeting, the Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal adopted, in decision BC-16/3 on technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants, the general technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants, on the basis of document UNEP/CHW.16/6/Add.1. The text of the technical guidelines, as adopted, is set out in the annex to the present note. The present note, including its annex, has not been formally edited.

Annex

General technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants

(Version of 4 May 2023)

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Abbreviations and acronyms

AOAC	Association of Official Analytical Chemists (United States of America)
ASTM	American Society for Testing and Materials
BAT	best available techniques
BCD	base-catalysed decomposition
BDE	bromodiphenyl ether
BEP	best environmental practices
CEN	European Committee for Standardization
CFCs	chlorofluorocarbons
CHD	catalytic hydrodechlorination
DDT	1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane (dichlorodiphenyltrichloroethane)
DE	destruction efficiency
DRE	destruction removal efficiency
DRI	direct reduced iron
ECD	electron capture detector
EPA	Environmental Protection Agency (United States of America)
ESM	environmentally sound management
ESWI	Expert Team to Support Waste Implementation
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FRTR	Federal Remediation Technologies Roundtable (United States of America)
GAC	granular activated carbon
GC	Gas chromatography
GEMS	Global Environment Monitoring System
GEF	Global Environment Facility
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
GPCR	gas-phase chemical reduction
HASP	health and safety plan
HBB	hexabromobiphenyl
HBCD	hexabromocyclododecane
HCB	Hexachlorobenzene
HCBD	hexachlorobutadiene
HCH	hexachlorocyclohexane
HRMS	high-resolution mass spectrometry/spectrometer
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ILO	International Labour Organization
IMO	International Maritime Organization
IPCS	International Programme on Chemical Safety
ISO	International Organization for Standardization
JESCO	Japan Environmental Storage & Safety Corporation
LRMS	low-resolution mass spectrometry/spectrometer
LTTD	low-temperature thermal desorption
LWPS	liquid waste pre-heater system
MSW	municipal solid waste
NFM	non-ferrous metal
NIP	national implementation plan (Stockholm Convention)
OECD	Organisation for Economic Co-operation and Development
OEWG	Open-ended Working Group of the Basel Convention
PAH	polycyclic aromatic hydrocarbon
PBB	polybrominated biphenyl
PBDD	polybrominated dibenzo- <i>p</i> -dioxin
PBDE	polybrominated diphenyl ethers (may also contain BDE that are not listed in the Stockholm Convention)
PBDF	polybrominated dibenzofuran
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo- <i>p</i> -dioxin
PCDF	polychlorinated dibenzo-furan
PCP	pentachlorophenol
PCT	polychlorinated terphenyl
Pd/C	palladium on carbon
PeCB	pentachlorobenzene
PFASs	per- and polyfluoroalkyl substances (includes PFOA, PFOS, and PFHxS)
PFHxS	perfluorohexane sulfonic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic acid
POP	persistent organic pollutant

POP-BDEs	brominated diphenyl-ethers listed in the Stockholm Convention: tetraBDE, pentaBDE, hexaBDE, heptaBDE, decaBDE
POP-PFASs	perfluoroalkyl substances listed in the Stockholm Convention: perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride; perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds; perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds
QA	quality assurance
QC	quality control
SCCPs	short-chain chlorinated paraffins
SCWO	supercritical water oxidation
SOP	standard operational procedure
TEAP	Technology and Economic Assessment Panel (of the Montreal Protocol)
TEQ	toxicity equivalence
TRBP	thermal reduction batch processor
UNECE	United Nations Economic Commission for Europe
UNIDO	United Nations Industrial Development Organization
UNEP	United Nations Environment Programme
WHO	World Health Organization
XRF	X-ray fluorescence

Units of measurement

$\mu\text{g}/\text{kg}$	microgram(s) per kilogram. Corresponds to parts per billion (ppb) by mass.
kg	kilogram
kW	kilowatt
kWh	kilowatt-hour
mg	milligram
mg/kg	milligram(s) per kilogram. Corresponds to parts per million (ppm) by mass.
MJ	megajoule
ms	millisecond
ng	nanogram
Mg	megagram (1,000 kg or 1 tonne)
Nm^3	normal cubic metre; refers to dry gas, 101.3 kPa and 273.15 K

I. Introduction

A. Scope

1. The present general technical guidelines provide guidance on the environmentally sound management (ESM) of wastes consisting of, containing or contaminated with persistent organic pollutants (hereinafter referred to as “POP wastes”), pursuant to several decisions of multilateral environmental agreements on chemicals and wastes.¹ This document supersedes the General technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (POPs) of June 2022.

2. These technical guidelines serve as an “umbrella” document and should be used in conjunction with the following specific technical guidelines:

(a) Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with polychlorinated biphenyls, polychlorinated terphenyls, polychlorinated naphthalenes or polybrominated biphenyls including hexabromobiphenyl (PCBs technical guidelines) (UNEP, 2017a);

(b) Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with the pesticides aldrin, alpha hexachlorocyclohexane, beta hexachlorocyclohexane, chlordane, chlordecone, dicofol, dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), hexachlorobutadiene, lindane, mirex, pentachlorobenzene, pentachlorophenol and its salts, perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride, technical endosulfan and its related isomers or toxaphene or HCB as an industrial chemical (Pesticide POPs technical guidelines) (UNEP, 2022a);

(c) Technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with 1,1,1-trichloro-2,2-bis (4-chlorophenyl)ethane (DDT) (DDT technical guidelines) (UNEP, 2006a);

(d) Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF), perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds, and perfluorohexane sulfonic acid (PFHxS), its salts, and PFHxS-related compounds (POP-PFAS technical guidelines) (UNEP, 2023);

(e) Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with hexabromodiphenyl ether and heptabromodiphenyl ether or tetrabromodiphenyl ether and pentabromodiphenyl ether or decabromodiphenyl ether (POP-BDEs technical guidelines) (UNEP, 2019a);

(f) Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with hexabromocyclododecane (HBCD technical guidelines) (UNEP, 2015b);

(g) Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with pentachlorophenol and its salts and esters (PCP technical guidelines) (UNEP, 2017b);

(h) Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with hexachlorobutadiene (HCB technical guidelines) (UNEP, 2019b);

(i) Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with short-chain chlorinated paraffins (SCCP technical guidelines) (UNEP, 2019c);

¹ Decisions IV/17, V/26, VI/23, VII/13, VIII/16, IX/16, BC-10/9, BC-11/3, BC-12/3, BC-13/4, BC-14/4, BC-15/6, and BC-16/3 of the Conference of the Parties to the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal; decisions I/4, II/10, III/8, IV/11, V/12, VI/5, VII/8, OEWG-8/5, OEWG-9/3, OEWG-10/4, OEWG-11/3, and the reports of meetings of the Open-ended Working Group of the Basel Convention OEWG-12/16/Add.1 and OEWG-13/11; 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-1/2, SC-2/6, SC-3/7, SC-4/10-18, SC-5/3, SC-6/13, SC-7/12, SC-7/13, SC-7/14, SC-8/10, SC-8/11, SC-8/12, SC-9/4, SC-9/11, SC-9/12, and SC-10/13 of the Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants.

(j) Technical guidelines on the environmentally sound management of wastes containing or contaminated with unintentionally produced polychlorinated dibenzo-*p*-dioxins, polychlorinated dibenzofurans, hexachlorobenzene, polychlorinated biphenyls, pentachlorobenzene, polychlorinated naphthalenes or hexachlorobutadiene (Unintentional POPs technical guidelines) (UNEP, 2019d).

3. The purpose of the general technical guidelines is:

(a) To provide overarching and common guidance on the ESM of POP wastes;

(b) To address provisions 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) on:

(i) The levels of destruction and irreversible transformation;

(ii) The methods that are considered to constitute environmentally sound disposal;

(iii) The concentration levels to define low POP content.

4. The guidelines also provide guidance on reducing or eliminating POP releases to the environment from waste disposal and treatment processes. Considerations pertaining to the environmentally sound disposal of POP wastes discussed in these guidelines include choices of pre-treatment since pre-treatment may be important when determining a disposal method.

5. 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 to the Stockholm Convention is provided under the Stockholm Convention. Guidelines on BAT and provisional guidance on BEP relevant to Article 5 and Annex C to the Stockholm Convention were adopted by the Conference of the Parties to the Convention at its third meeting, in 2007.

6. Table 1 indicates which specific POPs technical guidelines address each of the 30 POPs listed in Annex A, B or C to the Stockholm Convention.

Table 1: Stockholm Convention POPs listed in Annex A, B or C addressed by specific technical guidelines under the Basel Convention

Stockholm Convention POPs	Basel Convention POPs technical guidelines									
	General technical guidelines									
	PCBs technical guidelines	Pesticides technical guidelines	DDT technical guidelines	Unintentional POPs technical guidelines	POP-BDEs technical guidelines	HBCD technical guidelines	POP-PFASs technical guidelines	HCBD technical guidelines	PCP technical guidelines	SCCP technical guidelines
Aldrin		x								
Chlordane		x								
Chlordecone		x								
Decabromodiphenyl ether (BDE-209) present in commercial decabromodiphenyl ether (decaBDE)					x					
Dicofol		x								
Dieldrin		x								
1,1,1-Trichloro-2,2-bis(4-chlorophenyl)ethane (DDT)			x							
Endrin		x								
Heptachlor		x								
Hexabromobiphenyl (HBB)	x									

Stockholm Convention POPs	Basel Convention POPs technical guidelines									
	General technical guidelines									
	PCBs technical guidelines	Pesticides technical guidelines	DDT technical guidelines	Unintentional POPs technical guidelines	POP-BDEs technical guidelines	HBCD technical guidelines	POP-PFASs technical guidelines	HCBBD technical guidelines	PCP technical guidelines	SCCP technical guidelines
Hexabromodiphenyl ether (hexaBDE) and heptabromodiphenyl ether (heptaBDE)					x					
Hexabromocyclododecane (HBCD)						x				
Hexachlorobenzene (HCB)		x		x						
Hexachlorobutadiene (HCBBD)		x		x				x		
Alpha hexachlorocyclohexane (alpha-HCH)		x								
Beta hexachlorocyclohexane (beta-HCH)		x								
Lindane		x								
Mirex		x								
Pentachlorobenzene (PeCB)		x		x						
Pentachlorophenol (PCP) and its salts and esters		x							x	
Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds							x			
Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds							x			
Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF)		x					x			
Polychlorinated biphenyls (PCBs)	x			x						
Polychlorinated dibenzo- <i>p</i> -dioxins (PCDDs)				x						
Polychlorinated dibenzofurans (PCDFs)				x						
Polychlorinated naphthalenes (PCNs)	x			x						
Short-chain chlorinated paraffins (SCCPs)										x
Technical endosulfan and its related isomers		x								
Tetrabromodiphenyl ether (tetraBDE) and pentabromodiphenylether (pentaBDE)					x					
Toxaphene		x								

B. About POPs² and POP wastes

7. Most POPs are of anthropogenic origin and intentionally produced. Some POPs, such as HCB, PCNs, PeCB, PCDD and PCDF, listed in Annex C to the Stockholm Convention, are also unintentionally generated and released from anthropogenic or natural sources. The characteristics of POPs (toxicity, persistence and bioaccumulation), their long-range transport and ubiquitous presence in the environment, including ecosystems and in humans, were the impetus for the Stockholm Convention.

8. Intentionally produced POPs are being used or have been used in industrial processes, in products and in articles. Due to their characteristics, POPs listed in the Annexes of the Stockholm Convention need to be adequately managed to prevent them from entering the environment. While action is needed to address recently listed POPs, continued action is equally important to manage the other POPs and prevent their further perpetuation (Weber et al., 2015).

² Further information on the characteristics of POPs is available from several sources, including the Agency for Toxic Substances and Disease Registry (United States of America); the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities; and the International Programme on Chemical Safety (1995) of the World Health Organization (WHO).

9. It is important to recognize that even when POPs are adequately managed to “turn off the tap” at the beginning of POPs life cycles, waste management efforts are ongoing as POPs can last in products and waste streams for many decades. In addition, the improper management of POP wastes can lead to releases of POPs into the environment. Furthermore, some disposal technologies, such as incineration, can lead to the unintentional formation and release of POPs listed in Annex C of Stockholm Convention (see section IV.G).

10. Some of the listed chemicals under the Stockholm Convention, such as POP-BDEs, PFOS, PFOA, PFHxS, HBCD, PCP, and SCCPs, have brought attention to the use of POPs in products and articles, including consumer products and articles. The management of these products and articles upon becoming waste has introduced new challenges to Parties and stakeholders in their work to define strategies and approaches for their ESM and efforts to prevent, reduce or eliminate their releases. For example, recycled plastics containing POPs are unintentionally contributing to contamination of new plastic products, when POPs are not removed from the recycling stream (e.g., Kajiwara et al., 2022) (see section IV.G.4).

II. Relevant provisions of the Basel and Stockholm conventions

11. A number of multilateral environmental agreements provide frameworks to prevent and minimize releases of toxic chemicals and hazardous wastes. The Basel, Stockholm and Rotterdam conventions are a series of building blocks that dovetail to create a comprehensive life cycle approach to the management of hazardous chemicals and wastes. Together, these conventions guide decision makers in their actions to minimize and manage the risks to the environment from a range of chemicals, products and wastes.

12. A full list of international instruments related to POPs is listed in annex I. The following sections present a brief explanation and description of relevant Articles of the Basel and Stockholm conventions to illustrate their complementarity in addition to key obligations of their Parties.

13. Provisions of the Stockholm Convention complement the provisions for the management of hazardous wastes under the Basel Convention to form a comprehensive regime for managing POP wastes. Provisions from the two conventions are to be applied to POP wastes in making decisions about their ESM.

A. Basel Convention

1. General provisions

14. The Basel Convention, which entered into force on 5 May 1992, aims to protect human health and the environment against the adverse effects resulting from the generation, management, transboundary movements and disposal of hazardous and other wastes. It does this via a set of provisions on the transboundary movement of wastes and their ESM. In particular, the Basel Convention stipulates that any transboundary movement (export, import or transit) of wastes is permissible only when the movement itself and the planned disposal of the hazardous or other wastes are environmentally sound.

15. A set of provisions of the Basel Convention lays out Parties obligations to ensure the ESM of POP wastes. These are listed in paragraphs 16 to 18 below.

16. In 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”. Paragraph 4 defines disposal as “any operation specified in Annex IV” to the Convention. Paragraph 8 defines the 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 the adverse effects which may result from such wastes.”

17. 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 wastes, when notified pursuant to subparagraph (a).”

18. Article 4, paragraphs 2 (a) – (e) and 2 (g), and paragraph 8, contains key provisions of the Basel Convention directly pertaining to ESM, waste prevention and minimization and waste disposal practices aimed at mitigating adverse effects on human health and the environment:

Paragraphs 2 (a) – (e) and 2 (g): “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;

(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;

(e) Not allow the export of hazardous wastes or other wastes to a State or group of States belonging to an economic and/or political integration organization that are Parties, particularly developing countries, which have prohibited by their legislation all imports, or if it has reason to believe that the wastes in question will not be managed in an environmentally sound manner, according to criteria to be decided on by the Parties at their first meeting;”

“(g) Prevent the import of hazardous wastes and other wastes if it has reason to believe that the wastes in question will not be managed in an environmentally sound manner.”

Paragraph 8: “Each Party shall require that hazardous wastes or other wastes, to be exported, are managed in an environmentally sound manner in the State of import or elsewhere.”

19. The Ban Amendment entered into force 5 December 2019, and it provides that Parties listed in Annex VII to the Convention (members of the EU, OECD and Liechtenstein) shall prohibit transboundary movements to States not listed in Annex VII of hazardous wastes which are destined for operations according to Annex IV.A and hazardous wastes under Article 1.1(a) which are destined for operations according to Annex IV.B³.

2. POP-related provisions

20. Article 1 (“Scope of the Convention”) defines the types of waste that are subject to the Basel Convention. Subparagraph 1 (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”).

21. For a list of Annex I and Annex II wastes that may consist of, contain or be contaminated with a specific POP, refer to the specific technical guidelines pertaining to that POP.

22. Annex I wastes are presumed to exhibit one or more Annex III hazardous characteristics, which may include H4.1 “Flammable solids”, H6.1 “Poisonous (Acute)”, H11 “Toxic (Delayed or chronic)”, H12 “Ecotoxic”, or H13 “Capable, by any means, after disposal, of yielding another material, e.g., leachate, which possesses any of the characteristics listed above”, unless, through “national tests”, they can be shown not to exhibit such characteristics. National tests may be useful for identifying a particular hazardous characteristic listed in Annex III until such time as the hazardous characteristic is fully defined. Guidance papers for Annex III hazardous characteristics H11, H12 and H13 were adopted on an interim basis by the Conference of the Parties to the Basel Convention at its sixth and seventh meetings.

23. List A of Annex VIII to the Convention lists wastes that are “characterized as hazardous under Article 1, paragraph 1 (a), of this Convention.” However, designation of a waste on Annex VIII does not preclude the use of Annex III List of hazardous characteristics to demonstrate that a waste is not

³ For information on the status of individual Parties in relation to the amendment, please see the Status of Ratifications page on the Basel Convention website.

hazardous (Annex I, paragraph (b)). List B of Annex IX lists wastes that “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.”

24. For a list of Annex VIII waste entries that are applicable to a specific POP, refer to the specific technical guidelines pertaining to that POP.

25. 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

26. The Stockholm Convention on Persistent Organic Pollutants (POPs) is a global treaty aimed at protecting human health and the environment from persistent organic pollutants.

27. 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.”

28. 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; and

(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.

29. Article 3 also provides that parties may continue producing or using POPs listed in Annexes A and/or B for specific exemptions or acceptable purposes in accordance with the specific stipulations in these annexes, if such have been specified by the Conference of the Parties upon listing.

30. Article 5, paragraph (a) (i), of the Stockholm Convention requires the development and maintenance of source inventories and release estimates for unintentionally produced POPs.

31. Article 5, paragraph (b) requires to promote the application of available, feasible and practical measures that can expeditiously achieve a realistic and meaningful level of release reduction or source elimination.

32. Article 5, paragraph (c) requires each Party to promote the development and, where it deems appropriate, require the use of substitute or modified materials, products and processes to prevent the formation and release of the chemicals listed in Annex C, taking into consideration the general guidance on prevention and release reduction measures in Annex C and guidelines adopted by decision of the Conference of the Parties.

33. 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 this 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;

(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

34. 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)."

35. 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."

36. 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

37. As stated in Article 6, paragraph 2 (c), of the Stockholm Convention, the Conference of the Parties to the Stockholm Convention 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).”

38. Under the Stockholm Convention, POP wastes are, in accordance with Article 6, paragraph 1 (d) (ii), to be disposed of in such a way that the POP content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of POPs or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option, or the POP content is low, taking into account international rules, standards, and guidelines, including those that may be developed pursuant to paragraph 2, as well as relevant global and regional regimes governing the management of hazardous wastes.

39. The low POP content described in the Stockholm Convention is independent from the provisions on determination of hazardous waste and requirements for transboundary movements under the Basel Convention.

40. Low POP content definitions should be established taking into account the main objective of the Basel Convention and the Stockholm Convention, which is the protection of the environment and human health. The following have been recognized in the determination of low POP content (see European Commission, 2011; German Federal Environment Agency, 2015; European Commission, 2019a; European Commission, 2021; UNEP/CHW/OEWG.9/INF/9/Add.1⁴ and /Add.2⁵; and UNEP/CHW.13/INF/66⁶):

- (a) Environmental and human health considerations;
- (b) Availability of adequate capacity for analysis;
- (c) Range of concentrations in articles, materials and waste;
- (d) Limit values within national legislation;
- (e) Availability of treatment capacity;
- (f) Limitations of knowledge and data;
- (g) Economic considerations.

41. The provisional definitions of low POP content contained in table 2 below should be applied. The concentrations of POPs in waste should be determined in accordance with national or international methods and standards, except for PCDDs and PCDFs. Concentrations of PCDDs and PCDFs in waste must be expressed according to Annex C, part IV, paragraph 2, to the Stockholm Convention.

⁴ Draft updated general technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants: supporting document for the development of section III of the general technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants.

⁵ Draft updated general technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants: methodology for establishing low persistent organic pollutant content and its application in the European Union.

⁶ Supporting information on the concentration levels to define the low persistent organic pollutant content values for persistent organic pollutants listed in Annexes A, B and C to the Stockholm Convention.

Table 2: Provisional definitions of low POP content⁷

POP	Low POP content
Aldrin	50 mg/kg
Alpha-HCH, beta-HCH and lindane	50 mg/kg as a sum ⁸
Chlordane	50 mg/kg
Chlordecone	50 mg/kg
DDT	50 mg/kg
Dicofol	50 mg/kg
Dieldrin	50 mg/kg
Endrin	50 mg/kg
HBB	50 mg/kg
HBCD	100 mg/kg or 500 mg/kg or 1000 mg/kg
HCB	50 mg/kg
HCBd	100 mg/kg
Heptachlor	50 mg/kg
Hexabromodiphenyl ether and heptabromodiphenyl ether and tetrabromodiphenyl ether and pentabromodiphenyl ether	50 mg/kg or 1000 mg/kg as a sum ⁹
Hexabromodiphenyl ether and heptabromodiphenyl ether and tetrabromodiphenyl ether and pentabromodiphenyl ether and decabromodiphenyl ether (BDE-209) present in commercial decabromodiphenyl ether	[50 mg/kg as a sum] [500 mg/kg as a sum] [1000 mg/kg as a sum] ¹⁰
Mirex	50 mg/kg
PCBs	50 mg/kg
PCDDs and PCDFs ¹¹	1 µg TEQ/kg or 15 µg TEQ/kg [1 µg TEQ/kg or 5 µg TEQ/kg]
[PCDDs, PCDFs and dioxin-like PCBs ¹²]	[1 µg TEQ/kg] [5 µg TEQ/kg]
PCNs	10 mg/kg
PCP and its salts and esters	100 mg/kg
PeCB	50 mg/kg
PFOA, its salts and PFOA-related compounds	[50 mg/kg] [1 mg/kg (PFOA and its salts), 40 mg/kg (Sum of PFOA-related compounds)]

⁷ It is noted that work towards a review of the provisional low POP content values will be undertaken in accordance with decision BC-13/4.

⁸ The limit value has been set for the sum of lindane and its by-products alpha- and beta-HCH, because they may be contained together in pesticides and production wastes.

⁹ The limit value has been set for the sum of tetra-, penta-, hexa-, and hepta-BDE, because commercial mixtures have varying congener composition (see section I.B.1 of the POP-BDE guidelines), and for analytical efficiencies.

[¹⁰ The limit value has been set for the sum of tetra-, penta-, hexa-, hepta-, and decaBDE, because commercial mixtures have varying congener composition (see section I.B.1 of the POP-BDE guidelines), and for analytical efficiencies.]

¹¹ TEQ as referred to in Annex C, part IV, paragraph 2, to the Stockholm Convention [, [but only]for PCDDs [, and]PCDFs [and dioxin-like PCBs]].

¹² [TEQ as referred to in Annex C, part IV, paragraph 2, to the Stockholm Convention].

POP	Low POP content
	[0.025 mg/kg for PFOA and salts; 10 mg/kg for related compounds] [in Waste Aqueous Film Forming Foams (AFFF)] <ul style="list-style-type: none"> - 0.025 mg/kg for PFOA and its salts, and - 1 mg/kg for related compounds]
Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds	1 mg/kg (PFHxS and its salts), 40 mg/kg (sum of PFHxS-related compounds)
PFOS, its salts and PFOSF	[5 mg/kg or] 50 mg/kg
Short-chain chlorinated paraffins (SCCPs)	[100 mg/kg] [1 500 mg/kg] [10 000 mg/kg]
Technical endosulfan and its related isomers	50 mg/kg
Toxaphene	50 mg/kg

B. Levels of destruction and irreversible transformation

42. Destruction efficiency¹³ (DE) is the percentage of POP content within the waste destroyed or irreversibly transformed by a particular method or technology. Destruction removal efficiency¹⁴ (DRE) only considers emissions to air and is the percentage of original POPs irreversibly transformed and removed from gaseous emissions.

43. The provisional definition set out in paragraph 44 below recognizes the following:

(a) Both DE and DRE are a function of the initial POP content and do not cover any fraction of other unintentionally produced POPs during destruction or irreversible transformation;

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

(c) BAT and BEP are available in order to ensure the anticipated environmental performance is achieved, including expected DE;

(d) Pertinent national legislation,¹⁵ international rules, standards and guidelines apply to these operations.

44. 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:

(i) PCDDs and PCDFs: 0.1 ng TEQ/Nm³;¹⁶

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

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

¹³ 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., $DE = (\text{POP content within waste} - \text{POP content within gas, liquid and solid residual}) / \text{POP content within the waste}$.

¹⁴ 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 residues (stack emissions), divided by the mass of the POP content within the wastes, i.e., $DRE = (\text{POP content within waste} - \text{POP content within gas residual}) / \text{POP content within the waste}$.

¹⁵ For example, in Japan, the Ministry of the Environment in 2010 issued a "Technical Guideline for the Environmentally Sound Treatment of PFOS Wastes", which states that destruction levels for PFOS and its salts must be over 99.999 per cent (Ministry of the Environment of Japan, 2013b).

¹⁶ TEQ as referred to in Annex C, part IV, paragraph 2, to 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. Standardization at 10 per cent O₂ for cement kilns co-incineration.

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

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

C. Methods that constitute environmentally sound disposal

46. Section G of chapter IV below contains a description of methods that are considered to constitute environmentally sound disposal of POP wastes.

IV. Guidance on environmentally sound management (ESM)

A. General considerations

47. ESM is a broad policy concept that is understood and implemented in various ways by different countries, stakeholders and organizations. The provisions and guidance documents pertaining to ESM of hazardous wastes as it applies to POP wastes within the Basel and Stockholm conventions, together with performance elements produced by the Organisation for Economic Co-operation and Development (OECD), core performance elements provide for a common understanding and international guidance to support and implement the ESM of hazardous wastes and other wastes.

48. The 2013 *Framework for the environmentally sound management of hazardous wastes and other wastes* (“ESM framework”)¹⁷ (UNEP, 2013a) was adopted at the eleventh meeting of the Conference of the Parties to the Basel Convention. The framework establishes a common understanding of what ESM encompasses and identifies tools and strategies to support and promote the implementation of ESM. It is intended as a practical guide for governments and other stakeholders participating in the management of hazardous wastes and other wastes and constitutes the most comprehensive guidance on ESM to complement the Basel technical guidelines.

49. As presented in paragraph 16 of this document, Article 4 of the Basel Convention contains provisions related to the ESM of hazardous wastes and other wastes. ESM is also the subject of the following declarations:

(a) The 1999 Basel Declaration on Environmentally Sound Management, which was adopted at the fifth meeting of the Conference of the Parties to the Basel Convention 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;

(b) The 2011 Cartagena Declaration on the Prevention, Minimization and Recovery of Hazardous Wastes and Other Wastes, which was adopted at the tenth meeting of the Conference of the Parties to the Basel Convention and reaffirms that the Basel Convention is the primary global legal instrument for guiding the ESM of hazardous wastes and other wastes and their disposal.

50. Under the Stockholm Convention, the term “environmentally sound management” is not defined. Environmentally sound methods for disposal of POP wastes are, however, to be determined by the Conference of the Parties in cooperation with the appropriate bodies of the Basel Convention.

51. The 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 (OECD, 2004).

52. Parties should develop a range of measures (strategies, policies, legislation, regulations and programmes) and monitor their implementation to support the meeting of ESM objectives. The implementation of national strategies, policies and programmes are effective tools to complement the implementation of legislation and regulations; monitoring and enforcement; incentives and penalties; technologies; and other tools in which all key stakeholders participate and cooperate (UNEP, 2013a).

¹⁷ ESM framework:

<http://www.basel.int/Implementation/CountryLedInitiative/EnvironmentallySoundManagement/ESMFramework/tabid/3616/Default.aspx>.

The following sections should be taken into account when establishing, implementing or evaluating ESM.

B. Legislative and regulatory framework

53. Parties to the Basel and Stockholm conventions should examine their national strategies, policies, controls, standards and procedures to ensure that they are in agreement with the two conventions and with their obligations under them, including those that pertain to ESM of POP wastes.

54. Most countries already have in place some form of legislation that outlines broad environmental protection principles, powers and rights. Such legislation should make ESM operational and include requirements for protection of both human health and the environment. Such enabling legislation can give governments the power to enact and enforce specific rules and regulations on hazardous wastes, conduct inspections and establish penalties for violations.

55. Such legislation on hazardous wastes should also define hazardous wastes. Waste with a POP content at or above the low POP content specified in the definition referred to in section III.A should be considered in the definition, as appropriate.

56. The legislation could define ESM and require adherence to ESM principles, ensuring that countries satisfy provisions for ESM of POP wastes, 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

57. Legislation and voluntary commitments, as applicable, should differentiate between the phase-out dates for the production of POPs and their use¹⁹ in the manufacture of products and articles and the date by which the POPs (whether in pure form or in mixtures), products or articles should be disposed of once they have become waste²⁰. In addition, they should set a time limit for the disposal of POP wastes, taking into account that such products and articles may have long service lives. Examples of pertinent national legislation can be found in annex II.

2. Transboundary movement requirements²¹

58. 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.

59. 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

¹⁸ Further guidance on Basel Convention regulatory frameworks can be found in the following documents: Manual for the Implementation of the Basel Convention (UNEP, 2015f) and Basel Convention: Guide to the Control System (UNEP, 2015g). Parties to the Stockholm Convention should also consult the Guidance for Developing a National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants (UNEP, 2014).

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

²⁰ Note that Annex A note (ii) to the Stockholm Convention provides that: "Quantities of a chemical occurring as constituents of articles manufactured or already in use before or on the date of entry into force of the relevant obligation with respect to that chemical, shall not be considered as listed in this Annex, provided that a Party has notified the Secretariat that a particular type of article remains in use within that Party."

²¹ This applies only to the Parties to the Basel Convention.

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 be provided using the accepted notification form and that the approved consignment be accompanied by a movement document from the point where the transboundary movement commences to the point of disposal.

60. Parties listed in Annex VII to the Convention (members of the EU, OECD and Liechtenstein), that are bound by the Ban Amendment, shall prohibit transboundary movements to States not listed in Annex VII of hazardous wastes which are destined for operations according to Annex IV.A and hazardous wastes under Article 1.1(a) which are destined to operations according to Annex IV.B²².

61. Furthermore, hazardous wastes and other wastes subject to transboundary movements should be packaged, labelled and transported in conformity with international rules and standards.²³

62. When a 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 be made. In the case of illegal traffic (as defined in Article 9, paragraph 1), as the result of conduct on the part of the exporter or the generator, the country of export shall ensure that the wastes in question are taken back into the country of export for their disposal or otherwise disposed of in accordance with the provisions of the Basel Convention (as per Article 9, paragraph 2).

63. 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 Convention.

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

64. 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 and their relevant waste streams.²⁴ 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 safety²⁵

65. A legislative approach should be taken 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 (see e.g., UNEP, 2019e). While neither the Basel nor the Stockholm Convention specifically requires Parties to have worker health and safety legislation, the protection of human health underpins many of the objectives of both conventions.

66. 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 into such legislation. 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.

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

5. Specification of acceptable procedures for sampling and analysis of POPs

68. Various methods and protocols for sampling and analysis have been developed for a range of purposes. Reliable and useful data can be generated only when sampling and analytical methods

²² For information on the status of individual Parties in relation to the amendment, please see the Status of Ratifications page on the Basel Convention website.

²³ In this connection, the United Nations Recommendations on the Transport of Dangerous Goods (Model Regulations) of 2021 (Twenty-second revised edition UNECE, 2021) or later versions should be used.

²⁴ Parties should consult the guidelines pertaining to the storage of pesticides and pesticide waste that have been produced by the Food and Agriculture Organization (FAO) of the United Nations (FAO, 1996).

²⁵ See section IV.I.

appropriate to the waste are used. 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 in which it is found. The procedures specified should be agreed and accepted before any sampling or analysis takes place. The use of internationally accepted procedures is recommended. This should ensure that the reported results are acceptable and comparable. See section E of this chapter for further details.

6. Requirements for waste treatment and disposal facilities

69. 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 that must be maintained in order for such approvals to remain valid. It may be necessary to add requirements specific to POP wastes to meet the requirements of ESM and to comply with specific requirements of the Basel and Stockholm conventions.

7. General requirement for public participation

70. Public participation is a core principle of the 1999 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.

8. Contaminated sites

71. 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

72. Examples of other aspects of the life-cycle management of POP wastes that could be regulated 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

73. The prevention and minimization of POP wastes are the first and most important steps in the overall ESM of such wastes. In 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”. Waste prevention should be the preferred option in any waste management policy. According to the framework for the ESM of hazardous wastes and other wastes, the need to manage wastes and/or the risks and costs associated with doing so are reduced by not generating wastes and by ensuring that generated wastes are less hazardous (UNEP, 2013a).

74. According to the Basel ESM framework, companies that generate wastes (waste generators) are responsible for ensuring the implementation of BAT and BEP when undertaking activities that generate wastes. In doing so, they act to minimize the wastes generated by ensuring research, investment in design, innovation and development of new products and processes that use fewer resources and energy and that reduce, substitute or eliminate the use of hazardous materials.

75. Waste generators 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 and all POP wastes.

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

- (a) Identification of processes possibly unintentionally producing POPs (e.g., incineration) and determination of whether Stockholm Convention guidelines on BAT and BEP²⁶ are applicable;
- (b) Identification of processes that use POPs and generate POP wastes:
 - (i) To determine whether process modifications, including updating of older equipment or material, could reduce POP waste generation;
 - (ii) To identify alternative processes that are not linked to the production of POP wastes;
- (c) Identification of products and articles consisting of, containing or contaminated with POPs and non-POP alternatives; and
- (d) Minimization of the volume of POP wastes 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 POP wastes;
 - (iv) By isolation of POP wastes in order to prevent contamination of other materials;
 - (v) By adoption of appropriate procedures for decommissioning of facilities.

77. The mixing and blending of wastes with POP contents at or 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, the mixing or blending of materials prior to waste treatment may be necessary in order to enable treatment or to optimize treatment efficiency.

D. Identification of wastes

1. General considerations

78. The identification of POP wastes is the starting point for their effective ESM. POP wastes can be generated via a range of processes and activities that can occur during the whole life cycle of POPs, for example:

- (a) During their intentional manufacture (production facilities);
- (b) As by-products of industrial and other processes using these POPs (e.g., manufacturing facilities of products and articles such as plastics, upholstery, textiles, packaging materials, electrical/electronic equipment, masterbatches, pellets, expanded polystyrene materials, paints, adhesives, etc.);
- (c) Through contamination of materials or the environment as a result of accidents or leakage that may occur during production, sale, use, decommissioning, removal, transfer or disposal;
- (d) Through contamination of materials during handling, use of products and articles, such as containers, clothing and in some cases personal protective equipment (hazmat suits, boots, respirators, etc.) that have been contaminated through contact with a POP;
- (e) When products or articles consisting of, containing or contaminated with POPs are used, become off-specification, are unfit for their original use or have been banned, or when registrations for such products have been withdrawn; or
- (f) When products or articles consisting of, containing or contaminated with POPs are disposed of (e.g. incineration resulting in ash contaminated with unintentionally produced POPs).

79. POP wastes 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. Examples of such wastes are presented in table 3.

Table 3: Physical forms and types of POP wastes generated

Physical form of the wastes	Type of waste
Liquid	1. Obsolete liquid stockpile of pure POPs

²⁶ Drafts of guidance documents for specific POPs are available at <http://chm.pops.int/Implementation/BATandBEP/Guidance/tabid/3636/Default.aspx>.

Physical form of the wastes	Type of waste
	<ol style="list-style-type: none"> 2. Industrial wastewater 3. Municipal wastewater 4. Landfill leachate 5. Industrial liquid (e.g., solvent) 6. Liquid household products 7. Liquid fluids (e.g., insulating oils, lubricants, metalworking and hydraulic fluids) 8. Industrial sludge 9. Municipal sludge
Solid	<ol style="list-style-type: none"> 1. Obsolete solid stockpile of POPs 2. Waste generated from discontinued or exempt POPs production and processes involving POPs 3. Soil, sediment, rock and mine aggregates 4. Industrial waste (e.g., sludge, activated carbon and brine roasting residues from amalgam electrolysis units in chlor-alkali plants) 5. Municipal sludge 6. Other residues from wastewater cleaning (e.g., activated carbon treatment) 7. Residues from air pollution control system (e.g., fly-ashes) 8. Waste incineration residues (e.g. bottom ashes), other than those from air pollution control system²⁷ 9. Dust 10. Upholstery, textile, carpets, rubber, leather 11. Electrical and electronic equipment 12. Containers and packaging material 13. Contaminated material (e.g., clothing, personal protective equipment) 14. Vehicle and shredder vehicle fluff 15. Plastic, paper, metal, wood 16. Demolition material (painted materials, resin-based flooring, sealants, sealed glazing units, insulation boards) 17. Fire suppression foam equipment
Gas	<ol style="list-style-type: none"> 1. Landfill gas 2. Gas from incineration facilities 3. Gas from recycling facilities 4. Gas from certain (industrial) processes

80. In Article 6, paragraph 1, the Stockholm Convention requires each Party to:

(a) Develop appropriate strategies for the identification of stockpiles consisting of or containing chemicals listed either in Annex A or Annex B and of 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).

81. The list of source categories provided in Annex C to the Stockholm Convention can assist industrial managers and government regulators, and the general public, in identifying unintentionally produced POP wastes.

2. Inventories

82. Inventories are an important tool for identifying, quantifying and characterizing POP wastes.

83. Stockholm Convention articles 5, paragraph (a), 6, paragraph 1(a), and 11, paragraph 1, provide elements that contribute to the identification of waste-related sources of POPs. For the purpose of the ESM of wastes, a more specific and complete inventory may be needed.

²⁷ European Commission, 2005; Wang et al., 2010.

84. When developing an inventory, priority should be given to the identification of important waste streams in terms of high volume and high POP concentrations. National inventories may be used:
- (a) To establish a baseline quantity of products, articles and POP wastes;
 - (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.
85. For further information on the development of national inventories, consult the *Methodological guide for the development of inventories of hazardous wastes and other wastes under the Basel Convention* (UNEP, 2015d). The guide focuses on the actions recommended to develop the national information systems that produce the information needed to assist countries in fulfilling their reporting obligations under the Basel Convention.
86. Guidance documents for the inventory of specific POPs are also available (e.g., PCBs, PFOS, POP-BDEs, HBCD, HCBD, PCP, PCN, and SCCPs),²⁸ as is guidance for developing release inventories of unintentionally generated POPs (see Toolkit for Identification and Quantification of Releases of Dioxins, Furans and Other Unintentional Persistent Organic Pollutants under Article 5 of the Stockholm Convention (UNEP, 2013b). Guidance on sampling, screening and analysis of persistent organic pollutants in products and recycling (UNEP, 2021) may also be useful for the identification of waste.
87. In addition, it should be noted that the 2003 Protocol on Pollutant Release and Transfer Registers (PRTR) to the 1998 United Nations Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention) includes provisions pertaining to inventories that may be applicable to POPs. Moreover, it should be noted that, the Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean (ECLAC) establishes that each Party shall take steps to establish a PRTR covering air, water, soil and subsoil pollutants, as well as materials and waste in its jurisdiction. Reporting on POPs in waste transfers can take place in PRTRs at national level.²⁹

E. Sampling, analysis and monitoring

88. Sampling, analysis and monitoring are important activities in the management of POP wastes enabling the manager of the wastes and those who regulate its management to identify the concentration of POPs in some waste streams and select the appropriate management method. The activities may also be necessary to monitor if the methods of destruction chosen are operating within the set standards and to ensure that POPs are not released into the environment. Monitoring and surveillance serve as elements for identifying and tracking environmental concerns and human health risks. Information collected from monitoring programmes feeds into science-based decision-making processes and is used for the evaluation of the effectiveness of risk management measures, including regulations.
89. Sampling, analysis and monitoring should be conducted by trained professionals in accordance with a well-designed programme 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.
90. Each Party should identify its sampling, analysis and monitoring needs and ensure it has laboratory capacity that will meet the required operating standards. Training and protocols should be in place to ensure that these standards can be met and that quality data and meaningful results can be obtained. Building this capacity may be necessary in some countries if none exists.
91. Different analytical methods can be used depending on the purpose of the sampling or monitoring activity and the physical form of the waste. For information on good laboratory practices

²⁸ Guidance documents for the inventory of these specific POPs are available at <http://chm.pops.int/Implementation/NationalImplementationPlans/Guidance/tabid/7730/Default.aspx>, <http://chm.pops.int/Implementation/NationalImplementationPlans/Guidance/tabid/7730/Default.aspx>.

²⁹ Such reporting is part of PRTR in the Czech Republic (MŽP, 2017). Integrated Pollutants Releases Register. Retrieved 12-10-2017, 2017, from <http://www.irz.cz> (in Czech).

the OECD series (OECD, various years) and the Handbook on Good Laboratory Practices (WHO, 2009) may be consulted; on general methodological considerations, the Guidance for a Global Monitoring Programme for Persistent Organic Pollutants (UNEP, 2015a) may be used. Further information on POPs analysis may be obtained from the UNEP/Global Environment Facility (GEF) project on capacity needs for analyzing POPs³⁰.

1. Sampling³¹

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

93. Standardized 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 the 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.

94. Sampling should comply with specific national legislation, where it exists, or with international regulations and standards. 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 ISO, the American Society for Testing and Materials (ASTM), the European Union, the United States Environmental Protection Agency (US EPA), the Global Environment Monitoring System (GEMS), and the European Committee for Electrotechnical Standardization (CENELEC) (see Standard on Collection, logistics and treatment requirements for WEEE (Waste Electrical and Electronic Equipment) – Part 1: General Treatment Requirements, in particular specifications for de-pollution), and the European Committee for Standardization (CEN) (see EN 14899:2005 Characterization of waste - Sampling of waste materials - Framework for the preparation and application of a sampling plan and the series of CEN/TR 15310 1-5: 2006 Characterization of waste - Sampling of waste materials);
- (c) Establishment of quality assurance and quality control (QA/QC) procedures (see e.g. Cobban et al., 2020).

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

96. Types of waste matrices typically sampled for POPs include solids, liquids and gases:

- (a) Liquids:

³⁰ <https://www.thegef.org/project/assessment-existing-capacity-and-capacity-building-needs-analyze-pops-developing-countries>.

³¹ Further information on sampling is available in NordTest, 1995; NordTest, 1996; US EPA, 2002; and UNEP, 2017c; and Cobban et al., 2020).

- (i) Leachate from dumpsites and landfills;
- (ii) Liquid collected from spills;
- (iii) Water (surface water, drinking water and industrial and municipal effluents);
- (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;
 - (iv) Soil, sediment, rubble and compost;
 - (v) Consumer articles and products;
- (c) Gases:
 - (i) Air (indoor);
 - (ii) Air (emissions).

2. Analysis

97. Typically, POPs analysis is performed in a dedicated laboratory. In some situations, for example in remote areas, testing in the field can be made possible using test kits designed for screening purposes in the field.

98. For analysis in laboratories, there are several analytical methods available, although for some POPs analytical methods are still in development. Therefore, Parties should verify the availability and costs of methods for the POP they want to monitor before developing their monitoring and sampling programme. Methods of analyzing the various matrices for POPs have been developed by ISO, the European Committee for Standardization (CEN), US EPA, AOAC and ASTM. Most in-house methods are variations of these, and such in-house methods are also acceptable after validation. See also Stockholm Convention Guidance on Sampling, Screening and Analysis of Persistent Organic Pollutants (POPs) in Products and Recycling (UNEP, 2021) and Cobban et al. (2020).

99. The identification of a POP can be a difficult task, particularly when the POP consists of a number of congeners or even isomers.

100. A tiered approach for the analysis (for the purpose of identification and quantification of a POP) is recommended; this would begin with simple steps and thereafter involve more sophisticated methods. The first step is to identify wastes that potentially contain POPs in order to reduce the number of samples (and subsequently the amounts of waste to be disposed). The screening methods are especially valuable in situations where decisions need to be taken rapidly, or where there is a limited capacity, and also to reduce costs. In general, there are three steps, which sequentially include:

(a) Coarse screening for presence of halogens contained in a POP; these are chlorine (Cl), bromine (Br) or fluorine (F). The purpose of this step is to identify from a large amount of samples those that contain chlorine or bromine. Hand-held instruments are available to test for these halogens without “destroying” the sample; e.g., X-ray fluorescence (XRF) has the advantage of being non-destructive, multi-elemental, fast and cost-effective. XRF is applicable to a wide range of concentrations, although it is currently not validated for concentrations below 100 mg/kg; its main disadvantage is that analyses are generally restricted to elements heavier than fluorine (Br, Cl) and cannot detect a specific substance;

(b) Biological or chemical screening methods (applied if a sample is positive under step 1): Test kits or simple detection methods with less costly instrumentation are available to further reduce the number of samples which may contain POPs listed in the Stockholm Convention. The determination of organic chlorine with the DEXSIL³² test kits or the L2000 analyzer³³ is well established, as both methods are able to analyse POPs in oil or soil samples. Bioanalytical methods, such as CALUX,³⁴ are recognized for the detection of dioxin-like toxic equivalents. Also, fast

³² Information can be found at: DEXSIL test kits: <http://www.dexsil.com/products/>.

³³ L2000 Analyzer http://www.dexsil.com/products/detail.php?product_id=13.

³⁴ CALUX: <http://www.crl-freiburg.eu/dioxin/bioanalytical.html>.

extraction methods and use of short gas chromatography (GC) columns and a simple detector can be used to identify chlorinated POPs;

(c) The final step is the confirmation of the chemical analysis, which is typically required for all samples that result positive under step 2. Such analysis is done in chemical laboratories, which often are specialized for a certain group of POPs (e.g., pesticide POPs, dioxin-like POPs, POP brominated flame retardants, and POP-PFASs) and specialized to a certain matrix. Confirmatory chemical analytical methods have been developed by international and national organizations and include:

- (i) For pesticide POPs and PCBs: gas chromatography GC + electron capture detector (ECD), mass spectrometry (MS), or tandem mass spectrometry (MS/MS);
- (ii) For POP-BDEs, dioxin-like POPs: capillary GC + MS (for dioxin-like preferentially high-resolution);
- (iii) For POP-PFASs: liquid chromatography (LC) + (MS/MS);
- (iv) For HBCD: GC/MS, LC-MS and HPLC-MS. GC-FID (flame ionization detector) using a HBCD reference is also able to identify and quantify HBCD;
- (v) For HCBd: GC/MS and GC+ECD;
- (vi) For PCP and its salts and esters: Typical analytical detection uses GC+ECD, GC/MS, as well as LC/MS methods;
- (vii) For PCNs: GC/MS for water analysis;
- (viii) For SCCPs: GC with either high or low resolution electron capture negative ion mass spectrometry (GC/ECNI-MS), time-of-flight MS (TOF-MS), deuterodechlorination combined with high resolution GC – high resolution MS (HRGC-HRMS), LC-MS/MS.

101. It is important that the steps described in subsections (a) and (b) of paragraph 100 above do not generate false negatives and that any method comply with the level of interest for the analysis.

102. 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 assessments). Accreditation of the laboratory in accordance with ISO 17025 or other standards by an independent body is important. Indispensable criteria for obtaining high-quality results include:

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

103. 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.

104. For laboratory analysis of POPs, there is no single analytical method available. Furthermore, the achievable quantification limits for each substance can vary and strongly depend on the individual matrix to be analysed (German Federal Environment Agency, 2015).

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

106. The individual steps in the analytical determination include:

- (a) Extraction, e.g., by Soxhlet, pressurized solvent extraction, 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 liquid chromatography (LC) or gas chromatography (GC), which will provide sufficient separation of analytes;
- (d) Identification by suitable detectors such as an ECD or a mass-selective detector, or by either low-resolution mass spectrometry (LRMS) or high-resolution mass spectrometry (HRMS);

(e) Quantification in accordance with internal standard methodologies (for reference, see UNEP, 2015c; UNEP, 2017d);

(f) Reporting in accordance with regulation(s).

3. Monitoring

107. In Article 10 (“International Cooperation”), paragraph 2 (b), the Basel Convention requires Parties to “cooperate in monitoring the effects of the management of hazardous wastes on human health and the environment”. In Article 11, paragraph 1, the Stockholm Convention requires Parties, within their capabilities, at the national and international levels, to encourage and/or undertake appropriate monitoring pertaining to POPs.

108. Monitoring programmes should be implemented for facilities managing POP wastes, as they provide an indication of whether a hazardous waste management operation is functioning in accordance with its design and environmental regulations.

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

- (a) Plant materials and food;
- (b) Fish and wildlife;
- (c) Biological fluids (e.g. human breast milk, blood, urine);
- (d) Air (ambient, wet or dry deposition such as snow, ice, dust);
- (e) Water (e.g., leachate, wastewater);
- (f) Soil;
- (g) Sediment.

110. The information from the monitoring programme should be used to:

- (a) Detect any releases to or changes in the quality of the surrounding environment;
- (b) Ensure that different types of hazardous wastes are properly managed by the waste management operation;
- (c) Identify potential issues relating to possible release or exposure and determine whether adjustments to the management approach might be appropriate.

111. By implementing a monitoring programme, governments, regulators, municipalities and recycling and waste facility managers can identify problems and take appropriate measures to remedy them. Further information on monitoring can be found in the following documents: Monitoring and research under the Chemicals Management Plan (Government of Canada, 2011; Environment Canada, 2011); General Principles of Monitoring (European Commission, 2003); Guidance for a Global Monitoring Programme for Persistent Organic Pollutants (UNEP, 2015a); Ministry of the Environment of Japan, 2013a; German Federation/Länder Dioxin Database (German Federal Environment Agency Dessau-Roßlau, 2014); and Environmental Management Tool Kit for Obsolete Pesticides - Volume 5 (Cobban, et al., 2020).

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

112. Handling, collection, packaging, labelling, transportation and storage are critically important steps as the risk of a spill, leak or fire can be as great as at other stages of the life cycle of a POP.

113. Considerations and provisions unique to POP waste streams are presented in the specific POP technical guidelines when appropriate. A tailored approach for certain POP waste streams (e.g. articles and products that have become waste) is desirable considering their various sources, waste types, volumes and POP concentrations. This allows decision makers to consider the risks that various waste streams may pose at different stages of their management, and the appropriate actions that may be necessary to prevent, eliminate or minimize their impact on the environment. Best management practices are, in some cases, in the early stages of being developed or documented.

114. Where appropriate, procedures and processes for managing hazardous wastes should be considered for handling, collecting, packaging, labelling, transporting and storing wastes with a POP content at or above the low POP contents referred to in section III.A in order to prevent spills and leaks resulting in worker exposure, releases to the environment or exposure of the community.

115. Relevant information regarding the hazardous characteristics and risks of POP wastes should be collected and analysed in order to plan for the proper handling of such wastes, for example by consulting and following the instructions given on the chemicals they contain and related safety data sheets. For labelling and packaging, the United Nations Globally Harmonized System of Classification and Labelling of Chemicals (GHS) should be taken into account, accordingly

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

- (a) Manual for the Implementation of the Basel Convention (UNEP, 2015c);
- (b) International Maritime Dangerous Goods Code (IMO, 2018);
- (c) International Civil Aviation Organization (ICAO) Technical Instructions for the Transport of Dangerous Goods by Air (ICAO, 2017);
- (d) United Nations Recommendations on the Transport of Dangerous Goods Model Regulations.³⁵

117. For the following sections (1–6), detailed information can be obtained from destruction and decontamination technologies for PCBs and other POP wastes under the Basel Convention: A training manual for hazardous waste project managers (UNEP, 2002a).

1. Handling³⁶

118. The main concerns when handling POP wastes are human exposure, accidental releases to the environment and contamination of other waste streams with POPs. POP wastes should be handled separately from other types of waste in order to prevent contamination of other waste streams.

119. The handling of liquid wastes and other wastes as appropriate should include the following recommended practices:

- (a) Inspecting containers to detect aging and loss of containment, and appropriate repackaging and relabelling as necessary;
- (b) Handling wastes at temperatures below 25 °C, if possible, because of 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;
- (i) Treating all absorbents and solvent from triple rinsing, disposable protective clothing and plastic sheeting as wastes containing or contaminated with POPs when appropriate;
- (j) In the handling of wastes of articles and products containing POPs, care should be taken not to release POPs into the environment from such wastes;
- (k) Training staff in the correct methods of handling POP wastes.

2. Collection

120. Although large industries may be responsible for the proper management of the POP wastes that they generate or own, many smaller entities also possess such wastes. The POP wastes possessed

³⁵ European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR); European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN); Regulations concerning the International Carriage of Dangerous Goods by Rail (RID).

³⁶ Examples of guidelines on the safe handling of hazardous materials and accident prevention include those prepared by the International Labour Organization (ILO, 1993 and 2004) and OECD (2003).

by small entities may, in addition to wastes from articles and products containing POPs (see paragraph 122 below), include household- or commercial-size 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 third party to a developing country.

121. 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 POP wastes;
- (b) To allow enough time of operation of collection programmes for the complete collection of all potential POP wastes;³⁷
- (c) To include, to the extent practical, all POP wastes 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;
- (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 the separation of POP wastes from other waste streams.

122. Wastes from articles and products containing POPs should be collected separately from those wastes that do not contain POPs. Concerning waste electrical and electronic equipment that contains plastics containing POP-BDEs or HBCD, see section IV.F.2 of the POP-BDEs technical guidelines. Concerning HBCD wastes like insulation materials, packaging textile waste containing HBCD, see section IV.F.2 of the HBCD guidelines. Concerning waste containing SCCPs like PVC plastics, see section IV.F.2 of the SCCP technical guidelines.

123. Collection depots should not become long-term storage facilities for POP wastes.

3. Packaging

124. POP wastes, whether hazardous or not, should be properly packaged for ease of transport and as a safety measure to reduce the risk of leaks and spills.

125. Packaging of hazardous wastes falls into two categories: packaging for transport and packaging for storage. Packaging for transport is often controlled by national dangerous goods transportation legislation. For packaging specifications for transport, the reader should consult reference materials published by IATA, IMO, UNECE, and national governments.

126. Some general precepts for the packaging of POP wastes for storage are as follows:

- (a) POP waste should be properly packaged before transport or storage; however, wastes from products and articles containing POP-BDEs or HBCD that are typically used by consumers do not need specific packaging;
- (b) Packaging that is acceptable for transport is, in most cases, suitable for storage, unless more stringent storage requirements are specified;
- (c) Such wastes in their original product containers are generally safe for storage if the packaging is in good condition;
- (d) POP 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 their contents;
- (e) 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

³⁷ Complete collection may require the depots to operate either continuously or intermittently over several years.

placed in appropriate new or refurbished containers. All new or refurbished containers should be clearly labelled as to their contents;

(f) Smaller containers can be packaged together in bulk by placing them in appropriate or approved larger containers containing absorbent material;

(g) Out-of-service equipment containing POPs may or may not constitute suitable packaging for storage. The determination of its safety should be made on a case-by-case basis.

4. Labelling³⁸

127. Labelling of products containing POPs may be a necessary measure in order to effectively manage the products upon becoming wastes.

128. Labelling containers is a basic safety feature for liquid POP waste. Each waste container should be labelled to identify the container (e.g., ID number), the chemical, and its hazard level.

5. Transportation

129. POP wastes 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)”. In case the waste containing POPs is qualified as hazardous waste, persons transporting such wastes should be qualified and certified as carriers of hazardous materials and wastes.

130. 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.

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

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

6. Storage³⁹

133. According to Annex IV, sections A and B, of the Basel Convention, storage (operations D15 and R13) is a temporary operation that precedes other disposal operations. POP wastes, after having been appropriately packaged (see subsection IV.F.3 on packaging) should be stored safely, preferably away from drinking water winning areas, and in dedicated areas away from other materials and wastes. However, they could be stored together with other wastes if they were destined for a similar disposal operation as listed under section IV.G. Storage areas should be designed to prevent the release of POPs into the environment by any route. Storage rooms, areas and 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 as approved by the authorities, as appropriate.

134. Where necessary, POP wastes should be segregated at the source to ensure appropriate arrangements for collection, including the use of collection tanks, taking into account their hazardous characteristics and the risk of exposure that they present.

135. Some basic principles of safe storage of POP wastes 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 containers (shipping containers are often used for storage) should be stored inside a lockable fenced enclosure;

(c) Separate storage areas, rooms or buildings may be required for each type of POP waste, unless specific approval has been given for joint storage;

³⁸ 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 (2019). See also FAO, 2001; UNEP, 2015d; and UNEP, 2019e.

³⁹ Further information can be found in *Storage of Hazardous Materials: A Technical Guide for Safe Warehousing of Hazardous Materials* (UNEP, 1993) and *Pesticide Storage and Stock Control Manual* (FAO, 1996).

- (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 minimize volatilization, including cool temperatures, reflective roofs and sidings, a shaded location, etc. When possible, particularly in warm 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 of 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 in curbed, leak-proof areas. 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 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;
- (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;
- (q) The storage area for POP wastes should have reasonable access roads for transportation vehicles.

G. Environmentally sound disposal

136. The methods for destruction or irreversible transformation of the POP content of wastes with a POP content at or above the defined low POP content are described in subsection 2. The methods for disposal other than destruction or irreversible transformation of the POP content of wastes with a POP content at or above the defined low POP content, when destruction or irreversible transformation does not represent the environmentally preferable option, are described in subsection 3.

137. The methods for disposal other than referred to above for wastes with a POP content below the defined low POP content are described in subsection 4.

1. Pre-treatment⁴⁰

138. 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 subsections 2 and 3 below. There are other pre-treatment operations that may be applied. Pre-treatment operations prior to disposal in accordance with subsections IV.G.2 and IV.G.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 IV.G.2. When 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 IV.G.1–4, as appropriate.

(a) Adsorption and absorption

139. “Sorption” is the general term for both absorption and adsorption processes. Sorption is a pre-treatment method in which solids are used 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; for example, when contaminants are transferred from liquid phase onto granular activated carbon (GAC). GAC is widely applied in the removal of organic contaminants in wastewaters because of its effectiveness, versatility and relatively low-cost.

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

(b) Blending

141. The blending of waste to create a homogeneous feedstock prior to waste treatment may be appropriate in order to enable treatment or to optimize treatment efficiency. However, the blending of wastes with POP contents at or above a defined low POP content with other materials for the purpose of generating a mixture with a POP content below the defined low POP content is not environmentally sound.

(c) Desorption

142. Desorption includes chemical desorption and thermal desorption. Thermal desorption (e.g., through vacuum thermal recycling or the use of a toroidal bed reactor or a liquid waste pre-heater) is a technology that utilizes heat to increase the volatility of contaminants such that they can be removed (separated) from a solid matrix (typically soil, sludge or filter cake). Direct fired and indirect fired desorbers exist. Thermal desorption processes are also categorized into high temperature thermal desorption (HTTD) and low-temperature thermal desorption (LTTD) processes. In HTTD, wastes are heated between 320 °C and 550 °C and in LTTD between 90 °C and 350 °C. LTTD, also known as low-temperature thermal volatilization, thermal stripping and soil roasting is used for volatile and semi-volatile compounds and elements (most commonly light petroleum hydrocarbons) from contaminated media (most commonly excavated soils). Such processes have been used for the decontamination of non-porous surfaces of electrical equipment, such as transformer carcasses that formerly contained PCB-containing dielectric fluids, or fluorescent lamps that contained mercury. Thermal desorption of POP wastes may result in the unintentional formation of POPs which may require additional treatment of treated waste or off-gas released.

(d) Dewatering

143. Dewatering is a pre-treatment process in which water is partially removed 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.

(e) Dismantling/disassembling

144. Dismantling or disassembling is a pre-treatment in which equipment, components or assemblies are taken apart to separate materials to increase options for reuse, refurbishment, recycling, recovery and final disposal.

⁴⁰ Further information on pre-treatment can be found in the Basel technical guidelines on hazardous wastes- Physico-Chemical Treatment (D9) /Biological Treatment (D8) (UNEP, 2000b).

(f) Dissolution

145. Pre-treatment by which a waste (liquid, solid or gas) is dissolved into a solvent.

(g) Distillation

146. A process which separates a solvent from a mixture by applying thermal energy and vaporising components and then condensing that vapour in a subsequent stage. Through this process, the solvent is separated, thereby allowing for subsequent recovery of the solvent and the reduction of the volume of waste destined for final disposal using other processes.

(h) Drying

147. Drying is a pre-treatment that removes water or a solvent by evaporation from a solid, semi-solid or liquid waste. In general, a gas stream, e.g., air, applies the heat by convection and carries away the vapor as humidity. Vacuum drying can also be used when heat is supplied by conduction or radiation (or microwaves), while the vapor produced can be removed with a vacuum system.

(i) Mechanical separation

148. 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.

(j) Membrane filtration

149. Membrane filtration is a thin film separation of two or more components in a liquid and is used as an option for conventional wastewater treatment. It is a pressure- or vacuum-driven separation process in which contaminants may be rejected by an engineered barrier, primarily through a size-exclusion mechanism. Different classifications of membrane treatment applicable to POPs include nanofiltration and reverse osmosis.

(k) Mixing

150. Mixing materials, without blending, prior to waste treatment may be appropriate in order to enable treatment or to optimize treatment efficiency. However, the mixing of wastes with POP contents at or 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.

(l) Oil-water separation

151. Some treatment technologies are not suitable for aqueous wastes, while 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 separation and both may require treatment.

(m) pH adjustment

152. 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.

(n) Sedimentation

153. Sedimentation is a physical process whereby particles settle by gravity. Chemical agents can be added to facilitate the settling process.

(o) Size reduction

154. Some technologies can be used to process wastes only within a certain size limit. For example, some technologies may be used to 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. Size reduction can include crushing, shearing and grinding. 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 POP wastes. Precautions should therefore be taken to prevent subsequent contamination of POP-free waste streams.

(p) Solvent washing

155. 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.

(q) Stabilization and solidification

156. Stabilization and solidification are to be used in conjunction for them to be environmentally sound. The stabilization of waste refers to the chemical conversion of the hazardous constituents in the waste to less soluble, mobile or toxic materials. The solidification of waste refers to changes in the physical properties of the waste to increase its compressive strength, decrease its permeability and encapsulate its hazardous constituents. Many waste streams require pre-treatment or special additives prior to stabilization and solidification. Applicability trials and durability tests prior to both stabilization and solidification are advisable.

(r) Vaporization

157. The conversion of liquid or solid substances into a gaseous state prior to waste treatment may be appropriate in order to enable or optimize treatment efficiency.

(s) Volume reduction

158. The reduction of waste volume through compression or compaction to make the waste more condensed may be appropriate to facilitate waste handling, transport, storage and disposal.

2. Destruction and irreversible transformation methods

159. The following disposal operations, as provided for in Annex IV, sections A and 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:

- (a) D9: Physico-chemical treatment;
- (b) D10: Incineration on land;
- (c) R1: Use as a fuel (other than in direct incineration) or other means to generate energy;
- (d) R4: Recycling/reclamation of metals and metal compounds, but restricted to activities of primary and secondary metallurgy described in (k) below.

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

161. Subsections (a) to (k) below describe commercially available operations for the environmentally sound destruction and irreversible transformation of the POP content in wastes that are capable of achieving the levels of destruction and irreversible transformation referred to in section III.B.⁴¹ Table 4 below provides an overview of these operations whereby the contents in this table on POPs reflects the information from the paragraphs on waste types, in the subsections (a) to (k). Table 4 should be used in conjunction with the following subsections to gain a more fulsome understanding of the many factors to consider before making decisions concerning the use of destruction and irreversible transformation methods. It should be noted that pertinent national legislation applies to these operations and that the operations should be used in accordance with the BAT and BEP standards developed under the Stockholm Convention, as presented in the 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 (UNEP, 2007) and OECD (2020). Consequences of not conducting the operations according to the standards outlined in the BAT and BEP guidance can lead to the formation and release of POPs into the environment.⁴²

162. When selecting one of the operations in subsections (a) to (k) below, the provisions of Article 5 of the Stockholm Convention should be taken into account (see paragraphs 28(b) and 31 above).

163. Available information on the technologies, especially for more recent ones, is constantly evolving. Each facility operator may determine if an appropriate level of destruction and irreversible transformation will be achieved using a particular technology in given conditions.

164. Emerging technologies are not described in this subsection because their commercial availability and their performance with regard to destruction and irreversible transformation of POPs are not documented.

⁴¹ Further information regarding these current and emerging technologies can be found in: UNEP, 2004a; volumes A and B of UNEP, 2002a; USEPA, 2010; and at STAP, 2011; UNEP, 2007.

⁴² For example, a contamination of the food chain in the surrounding of a cement kiln co-incinerating HCB wastes and a hazardous waste incinerator that incinerated HCB wastes have occurred (Weber et al., 2015).

165. For assessing the performance of the operations in subsections (a) to (k) below, a minimum DE of 99.999 per cent, with 99.9999 per cent of DRE as a supplement requirement where applicable, provides practical benchmark parameters for assessing disposal technology performance. Higher demonstrated DEs may be preferred on a case-by-case basis. As neither DE nor DRE take into account the potential transformation of the original POP to an unintentionally produced POP, potential releases of unintentionally produced POPs should be considered when choosing a particular operation.

Table 4: Overview of technologies for the destruction and irreversible transformation of POPs in wastes.

Technology	POPs										
	HBB	HBCD	HCB, HCBD and PeCB	PCB	PCDDs/PCDFs	PCN	PCP	Pesticides POPs	POP-PFASs	POP-BDEs	SCCPs
(a) Alkali metal reduction	ND*	ND	ND	Yes	ND	ND	ND	Yes for Chlordane, HCH	ND	ND	ND
(b) Advanced solid waste incineration (ASWI)	ND	Yes	ND	ND	ND	ND	Yes	ND	ND	Yes	Yes
(c) Base catalyzed decomposition (BCD)	ND	ND	ND	Yes	Yes	ND	Yes	Yes	ND	ND	ND
(d) Catalytic hydrodechlorination (CHD)	ND	ND	ND	Yes	Yes	ND	ND	ND	ND	ND	ND
(e) Cement kiln co-incineration	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(f) Gas phase chemical reduction (GPCR)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(g) Hazardous waste incineration	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(h) Plasma arc	ND	ND	ND	Yes	ND	ND	ND	Yes, for most pesticides, including chlordane, chlordecone, DDT, endosulfan, heptachlor	ND	ND	ND
(i) Plasma melting decomposition method (PMD)	ND	ND	ND	Yes	ND	ND	ND	ND	ND	ND	ND
(j) Supercritical water oxidation (SCWO) and subcritical water oxidation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(k) Thermal and metallurgical production of metals	ND	ND	ND	ND	Yes	ND	ND	ND	ND	Yes	ND

* ND stands for “not determined” and indicates that information is not available in the literature referred to in this document to confirm the use of the technology for certain POPs.

(a) Alkali metal reduction⁴³

166. *Process description:* Alkali metal reduction involves the treatment of wastes with dispersed alkali metals. Alkali metals react with chlorine in halogenated waste to produce salts and non-halogenated waste. Typically, the process operates at atmospheric pressure and at temperatures of between 60 °C and 180 °C (Ariizumi et al.1997). Treatment can take place either in situ (e.g., in the case of PCB-contaminated transformers), or ex situ in reaction vessels. There are several variations of this process (Piersol, 1989). Although potassium and potassium-sodium alloy have been used as

⁴³ Additional information is available in UNEP, 1998; UNEP, 2000a; UNEP, 2004a; and STAP, 2011.

reducing agents, metallic sodium is the most commonly used reducing agent. The information discussed in the remainder of this subsection is based on experiences with the use of metallic sodium.

167. *Efficiency:* Destruction efficiencies (DEs) of more than 99.999 per cent and destruction removal efficiencies (DREs) of 99.9999 per cent have been reported for chlordane, HCH 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 mg/kg in solid and liquid residues (UNEP, 2004b).

168. *Waste types:* Sodium reduction has been demonstrated with PCB-contaminated oils containing concentrations up to 10,000 mg/kg. Some vendors have claimed that this process is capable of treating whole capacitors and transformers (UNEP, 2004a). It is also reported that alkali metal reduction is applicable to chlordane and HCH as waste pesticides (Ministry of the Environment of Japan, 2004).

169. *Pre-treatment:* Ex-situ treatment of PCBs can be performed following solvent extraction of PCBs. Treatment of whole capacitors and transformers could be carried out following size reduction through shearing. Pre-treatment should include dewatering by phase separation, evaporation, or other method (UNIDO, 1987) to avoid explosive reactions with metallic sodium. Equipment should be washed with organic solvents. Similarly, the POPs that are in a solid or adsorbed form would need to be dissolved to the required concentration or extracted from their matrices (Piersol, 1989 and UNEP, 2004a).

170. *Emissions and residues:* Air emissions include nitrogen and hydrogen gas. Emissions of organic compounds are expected to be relatively minor (Piersol, 1989). 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, 2004b). Residues produced during the process include sodium chloride, sodium hydroxide, polyphenyls and water. In some variations, a solidified polymer is also formed (UNEP, 2000a).

171. *Release control and post-treatment:* After a reaction, the resulting 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 (UNEP, 2000a), with no or minimal post-treatment required. Depending on the technology used, the combination of filtration and centrifugation can include off-gas treatment and neutralization or conservation of residuals. The excess sodium, if not neutralized, may need to be recovered. Liquid products, if not reused, and solidified polymeric products should be usually burnt in incinerators, and inorganic salts would require disposal. Minor quantities of volatile organic compounds in emissions can be captured with the use of activated carbon (UNIDO, 2007).

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

173. *Material requirements:* Sodium is required to operate this process (UNEP, 2004a).

174. *Portability:* The process is available in transportable and fixed configurations (UNEP, 2000a).

175. *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 the process design and operation to exclude any water (and certain other substances, e.g., alcohols) from the waste and to prevent any contact of water (or certain other substances) with the metallic sodium.

176. *Capacity:* Mobile facilities are capable of treating 15,000 litres per day of PCB-contaminated transformer oils (UNEP, 2000a).

177. *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 (UNEP, 2000a).

178. *State of commercialization:* Alkali metal reduction has been used commercially for about 25 years and is still in use today. In Japan, three commercial-scale facilities were installed in 2004, 2005 and 2009 and are currently in operation (JESCO, 2009a; JESCO, 2009b; JESCO, 2013). Plants are also in France, Iran, Russian Federation, and Spain.

(b) Advanced Solid Waste Incineration (ASWI)

179. *Process description:* There are many different types of municipal waste incinerators and not all municipal waste incinerator technologies or facilities are able to properly destroy POPs in waste. Advanced solid waste incinerators are designed to safely treat the contaminants present in municipal solid waste (MSW) and similar commercial and industrial waste, usually in grate furnaces operating at high temperatures, and incorporating state-of-the-art pollution-control methods. Advanced solid waste incineration processes involve maintaining a minimum temperature of 850 °C in the combustion chamber(s) with a residence time in the gas phase of at least two seconds.

180. There are also incineration facilities dedicated to wood waste that are able to incinerate wood waste containing or contaminated with PCP. PCP treated wood combusted at 910-1025 °C resulted in no detectable chemicals in the off-gas (European Commission, 2011). According to the Swedish Environmental Protection Agency (2009), the controlled combustion conditions under which most wood and wood-based materials are incinerated in Sweden destroy dioxins and other chlorinated aromatic substances in the treated timber.

181. The conditions and operating requirements of the processes described in paragraphs 179 and 180 above should be stringent and meet the levels of destruction and irreversible transformation set out in subsection IV.G.2. Some countries have included such requirements in their legislation⁴⁴ or guidance documents.

182. In order to properly destroy the HBCD contained in waste a temperature higher than 850 °C is necessary. In the case of a full-scale test trial of the treatment of polystyrene foam (EPS and XPS) waste containing HBCD in the Würzburg Municipal Solid Waste Incinerator (Germany), where the input contained 1-2 weight-per cent of such foam waste containing 6,000 to 21,000 mg/kg of HBCD, the necessary combustion temperature was 900–1,000 °C (Mark et al., 2015). In the case of a full scale test trial of the treatment of e-waste in the Tamara Municipal Solid Waste Incinerator (Germany), where the input contained 0.5-1% of bromine including POP-BDEs, the temperature was 1,000 °C (Vehlow et al., 2002). These trial results were confirmed by a full scale facility study conducted in Norway, where waste containing brominated flame retardants was fed into a municipal solid waste incinerator at levels of 0, 5%, 10% and 20% brominated waste (corresponding to approximately 0.05, 0.1 and 0.2% bromine) (Borgnes & Rikheim, 2005). In the case of incineration or co-incineration of hazardous waste with a content of more than 1 per cent of halogenated organic substances expressed as chlorine, a temperature of at least 1,100 °C is required. Cable waste containing chlorinated paraffins was incinerated with ordinary municipal solid waste in a municipal solid waste incineration plant in Hamburg. Chlorinated paraffins were destroyed in the combustion chamber (~850 °C) (PE Europe GmbH, 2010).

183. During incineration, flue gases are released that contain most of the available fuel energy as heat. The organic substances in the waste burn as soon as they reach the ignition temperature. It is noted that it may be necessary to add other fuels in order to adjust the temperature during incineration as well as during the starting up and shutting down of furnaces.

184. It should be noted that residual waste typically contains heavy metals, sulfur and chlorine and may contain flame retardants in plastic or textile waste or waste containing PFASs. These substances are found in practically all fractions of residual waste and in a variety of chemical compounds. For this reason, the requirements for technical systems ensuring safe residual waste treatment are highly complex (Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, 2010).

185. The guidance on BAT/BEP developed by the Stockholm Convention relevant to Article 5 and Annex C should be used and applied to this technology (UNEP, 2007). See also OECD (2020).

186. *Efficiency:* Under appropriate combustion conditions, organic compounds are destroyed during incineration (European Commission, 2005). Reports by the Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol on Substances that Deplete the Ozone Layer, in particular a 2002 report of the TEAP Task Force on Destruction Technologies (TFDT), has shown the high destruction efficiency of ASWI for halogenated substances such as CFCs and HCFCs in polystyrene foams.

⁴⁴ European Commission, 2019b and EU Directive 2010/75/EU on industrial emissions, chapter 4. The directive is aimed at minimizing pollution from various industrial sources throughout the European Union. Operators of industrial installations engaged in activities covered under Annex I to the Directive are required to obtain an integrated permit from the authorities of EU countries.

187. In the full-scale test trial at the Würzburg Municipal Solid Waste Incinerator it was shown that ASWI was able to destroy HBCD with a DE of 99.999 per cent for EPS and XPS foams (Mark et al., 2015). In a mass-balance study using commercial scale industrial waste incineration plants (Kajiwara et al., 2017), DE of 99.999% was achieved with XPS/waste mixing ratios of up to approximately 3 % (w/w). Controlled combustion is demonstrated to achieve a DE greater than 99.9 and 99.99 per cent for treated wood containing PCP (European Commission, 2011; Lee and Valenti, 1998, respectively). DE for PBDEs in ASWI was calculated at 99.99% (Borgnes and Rikheim, 2005; Mark et al., 2006). In the case of full-scale test trials at two commercial-scale incinerators in Japan on the treatment of WEEE plastic mix containing approximately 50,000 mg/kg of decaBDE, DEs of over 99.9999% were achieved with WEEE plastics/waste mixing ratios of approximately 3% (w/w) (Kajiwara et al., 2021).

188. The efficiency of incineration to destroy PFAS compounds and the tendency for formation of fluorinated or mixed halogenated organic compounds is not well understood. It is likely that fluorinated organic compounds require higher temperatures to achieve 99.99% destruction in 1 second residence time than their chlorinated counterparts (US EPA, 2020a).

189. *Waste types:* Advanced solid waste incinerators are designed to incinerate MSW, including residual waste, but can also treat some waste from industry and commerce. A full-scale test trial showed that an ASWI was suitable for the incineration of polystyrene foam (EPS and XPS) waste containing HBCD. ASWI has been demonstrated to treat waste containing POP-BDEs (Borgnes and Rikheim, 2005; Vehlow, 2002; OECD, 1998; European Commission, 2011) as well as SCCPs (PE Europe GmbH, 2010). Wood waste containing or contaminated with PCP can be incinerated in incineration facilities dedicated to wood waste (European Commission, 2011; German Federal Environment Agency, 2015).

190. *Pre-treatment:* Waste should be mixed in a bunker in order to keep its calorific value constant. Volume reduction (crushing or shredding) is needed for bulky waste.

191. *Emissions and residues:* Emissions include carbon dioxide, water vapour, hydrogen chloride, hydrogen fluoride, sulfur-dioxide and other oxides of sulfur, particulates, nitrogen oxides, total organic carbon (TOC), PCDD/PCDF, heavy metals and carbon monoxide (European Commission, 2019c), and could also include PBDD/PBDF (UNEP, 2007). Other emissions include hydrogen bromide and PXDD/PXDF (Mark et al., 2015). Incinerators applying BAT that, *inter alia*, are designed to operate at high temperatures, to minimize the reformation of PCDDs and PCDFs and to transfer PCDD and PCDF from gaseous emissions to fly ash (e.g., with the use of activated carbon filters) have led to PCDD and PCDF emissions to air and discharges to water that are typically within regulatory limits (UNEP, 2007; European Commission 2019c). It is still a matter of scientific debate whether co-combustion of brominated flame retardants leads to increased emissions of chlorinated PCDD/PCDFs (Schüler and Jager, 2004). One study found that increasing the brominated waste content caused no significant increase in the emissions of chlorinated dioxins, or either brominated and chlorinated/brominated dioxins (Borgnes and Rikheim, 2005). However, another study found that introducing bromine for co-incineration dramatically increased formation of PBDD/PBDF and that formation rates of PCPh, PCBz and PCDD/F in the heat exchanger indicate considerable new formation of dioxins takes place through de novo synthesis (Schüler and Jager, 2004). The emission measurement results indicate that the incineration efficiency and the operating conditions of the air pollution control systems are of greater importance to the resulting emission levels of dioxins, rather than the bromine content level. Recent studies using commercial-scale incinerators have shown that emissions of PBDD/PBDFs in flue gas and ash during co-incineration of BFR-containing products were comparable to the baseline test without BFR-containing products indicating that, even if PBDD/PBDFs are synthesized as by-product in the furnace, their emissions can be sufficiently reduced through appropriate flue gas treatment (Kajiwara et al., 2017; 2021).

192. Generation of low molecular weight PFASs (including PFOS and PFOA, and PFHxS) in destruction of fluoropolymers (polytetrafluoroethylene (PTFE)) under typical waste incineration conditions was studied at the BRENDA pilot plant at Karlsruhe Institute of Technology (KIT) (Aleksandrov et al., 2019). No statistically significant evidence was found that PFOS, PFOA, or PFHxS was created during the incineration of PTFE. Formation of fluorinated or mixed halogenated organic compounds in the incineration of PFAS compounds is not well understood. Incomplete destruction of PFAS compounds can result in the formation of smaller PFAS products, or products of incomplete combustion, which may not have been researched and thus could be a potential chemical of concern (US EPA, 2020a). In an incineration residuals study of 27 Swedish waste incineration plants, PFASs were found in bottom ash in 9 plants sampled, in fly ash of 15 plants and in condensate water of 13 plants. The concentration of PFOS in fly ash from two incineration facilities was 3.74 and 3.44 µg/kg, and levels of PFASs in the pooled fly ash samples from 15 furnaces were in concentrations between 0.18 to 37.71 µg/kg. PFAS concentrations in bottom ash were 0.22-12.76

µg/kg and in condensate water 0.28-182.95 ng/L (Strandberg et al., 2021). It is not known which results represent advanced solid waste incineration facilities.

193. Brominated flame retardants have been found in the bottom and fly ash of the incineration plants. Wang et al. (2010) found 78 ng/g PBDEs in bottom ash when BFRs containing waste was incinerated. The fly ashes contained substantially lower concentrations of PBDEs than the bottom ash. In the mass flow analysis of HBCD destruction in commercial-scale industrial waste incineration plants, a large part of undecomposed HBCD ended up in the bottom ash (Kajiwara et al., 2017).

194. In residues, PCDDs and PCDFs are mainly found in fly ash and flue gas cleaning residues, in the range from 0.0008 to 35 ng TEQ/g, while bottom ash (representing the largest mass flow of residues from waste incineration) and scrubber water sludge contain a comparably small amount of PCDDs and PCDFs (European Commission, 2005). According to the facility study conducted in Norway, emission to air of polybrominated diphenyl ethers was 3,5 ng/Nm³ (Borgnes and Rikheim, 2005).

195. *Release control and post-treatment:* Process gases usually require treatment to remove hydrogen chloride and fluoride, sulfur and nitrogen oxides, heavy metals and particulate matter, and to prevent the formation of, or remove, unintentionally produced POPs. This can be achieved through the combined use of cleaning equipment, including electrostatic precipitators, fabric filters, scrubbers, selective catalytic or non-catalytic reduction, and carbon adsorption. Depending upon their characteristics including POPs concentrations, bottom and fly ashes may require disposal within a specially engineered landfill or permanent storage in underground mines and formations, or may be used for backfilling in salt mines (European Commission, 2019c).

196. The channelled emissions to the air of PCDD/Fs and dioxin-like PCBs from incineration of waste should be monitored with at least the frequency of once every six months for short-term sampling and of once every month for long-term sampling if the emission levels are not proven to be sufficiently stable (European Commission, 2019b; European Commission, 2019c).

197. In some cases, the channelled emissions to the air of PBDD/Fs may need to be monitored. For example, in the EU, for PBDD/Fs, a monitoring frequency of at least once every six months is required, but only in case the waste contains brominated flame retardants or when there is continuous injection of bromine to reduce mercury emissions to air (European Commission, 2019b; European Commission, 2019c).

198. *Energy requirements:* The amount of combustion fuel required depends on the composition of the waste to be treated and the flue gas treatment technologies to be applied.

199. *Material requirements:* Material requirements may include lime, sodium bicarbonate, activated carbon and other suitable materials for the removal of acid gases and other pollutants.

200. *Portability:* ASWI facilities are fixed units.

201. *Health and safety:* To ensure that appropriate health and safety measures are taken, ASWI facilities should be designed and operated in accordance with to the relevant chapters of EU Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) and the European Commission Best Available Techniques Reference Document (BREF) on Waste Incineration (see section 2.8.5 on “overview of safety devices and measures.”) (European Commission, 2019c)

202. *Capacity:* Each ASWI facility can treat between 30,000 and more than 1,000,000 tonnes of waste per year. Due to the high volume of HBCD-containing PS foams (which have a high volume and densities between 15 and 40 kilogram/cubic meters), the use of 1-2 per cent by weight of such foams, which corresponds to about 15 per cent to 30 per cent by volume, is recommended (Mark et al., 2015).

203. *Other practical issues:* There are no practical issues to report at this time.

204. *State of commercialization:* There is a long history of experience with advanced solid waste incineration (European Commission, 2019c).

(c) Base-catalysed decomposition (BCD)⁴⁵

205. *Process description:* The BCD process involves treatment of wastes in the presence of a reagent mixture consisting of a hydrogen-donor oil, an alkali metal hydroxide and a proprietary catalyst. When

⁴⁵ 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; STAP, 2011, UNEP, 1998; UNEP, 2001; UNEP, 2004a; US EPA, 2010; and Vijgen, 2002.

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 toxicity to the compounds.

206. *Efficiency*: DEs of 99.99–99.9999 per cent have been reported for DDT, HCB, PCBs, PCDDs and PCDFs (UNEP, 2000a), HCH and PCP (UNEP, 2004c). DEs greater than 99.999 per cent and DREs greater than 99.9999 per cent have also been reported for chlordane and HCH (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 (UNEP, 2001).

207. *Waste types*: BCD should be applicable to other POPs in addition to the ones listed in the previous paragraph (i.e., DDT, PCBs, PCDDs and PCDFs) (UNEP, 2004a and Vijgen, 2002). 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 by weight (Vijgen, 2002). Although there have been reports that the formation of salt within the treated mixture could limit the concentration of halogenated material that could be treated with BCD, more recent reports suggest that this problem has been overcome (see paragraph 218 below).

208. *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.

209. *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. Water will need to be evaporated from aqueous media, including wet sludge, prior to treatment. Capacitors can be treated following size reduction through shredding. If volatile solvents are present, as is the case with pesticides, they should be removed by distillation prior to treatment (CMPS&F – Environment Australia, 1997).

210. *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, 2004b). 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, refer to the literature produced by BCD Group Inc.

211. *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 (UNEP, 2004a). In addition, BCD facilities are equipped with activated carbon traps to minimize releases of volatile organic compounds in gaseous emissions.

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

213. *Material requirements*:

- (a) Hydrogen-donor oil;
- (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 (CMPS&F – Environment Australia, 1997). 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.

214. The *equipment* associated with this process is thought to be readily available (Rahuman et al., 2000).

215. *Portability*: Modular, transportable and fixed facilities have been built.

216. *Health and safety*: In general, the health and safety risks associated with operation of this technology are thought to be low, although a BCD facility 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. Some associated pre-treatments such as alkaline pre-treatment of

capacitors and solvent extraction present significant risks of fire and explosions, but those risks can be minimized through the application of appropriate precautions (CMPS&F – Environment Australia, 1997).

217. *Capacity*: BCD can process up to 2,500 gallons of waste per batch and can treat two–four batches per day (Vijgen, 2002).

218. *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 lower-chlorinated congeners are more toxic than higher-chlorinated congeners. It is therefore important that the process be appropriately monitored to ensure that the reaction reaches completion. In the past, it was reported that the BCD process was unable to treat high-concentration wastes because of salt build-up (CMPS&F – Environment Australia, 1997). More recently, however, it has been reported that this problem has been overcome (Vijgen, 2002; UNEP, 2004a).

219. *State of commercialization*: BCD has been operating in Mexico since 1999. In addition, BCD systems have been used in projects in Australia, Czech Republic, Spain, and the United States of America.

(d) Catalytic hydrodechlorination (CHD)

220. *Process description*: CHD involves the treatment of wastes with hydrogen gas and a 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. PCBs are transformed into biphenyls and hydrochloric acid (Murena et al., 2000). The process operates at atmospheric pressure and at temperatures of between 180 °C and 260 °C (Sakai et al., 2001; Noma et al., 2002; and Noma et al., 2003a and 2003b).

221. *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.

222. *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 all chlorinated compounds can be treated using CHD (McNamara, 2016).

223. *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.

224. *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 toxic materials in significant levels.

225. *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 in the next reaction.

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

227. *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.

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

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

230. *Capacity*: In Japan, a facility capable of treating 2 tonnes PCB per day using the CHD process was constructed and is in operation. Facilities are also operated in Canton, United States of America, and Bomen, Australia. Reportedly the 2016 capacity of the US plant in Canton was 45 million litres per year and that of the Bowen Australia plant 6.5 million litres per year (Hydrotec, 2018).

231. *Other practical issues*: There are many reports about PCB dechlorination using CHD. Generally, Pd/C catalysts show the largest degradation rates compared to the other supported metal catalysts. Reaction temperatures can be increased to 260 °C when paraffin oil is used as a reaction solvent.

232. *State of commercialization:* In Japan, a commercial-scale facility was constructed at the Japan Environmental Storage & Safety Corporation (JESCO) Osaka facility in 2006 and PCB extracted from transformers and capacitors are treated using the CHD process (JESCO, 2009c).

(e) **Cement kiln co-incineration⁴⁶**

233. *Process description:* Cement kilns typically consist of a long cylinder of 50–150 metres in length, 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 material temperatures reach 1,400 °C–1,500 °C. As the materials move through the kiln, they undergo drying and pyroprocessing reactions to form clinker. The length of the kiln ensures a sufficient residence time of the incineration gases at high temperatures: about 8 s at temperatures above 1200 °C (Vermeulen et al., 2011; USEPA, 2020b).

234. Cement kilns treating wastes may require kiln modifications (CMPS&F – Environment Australia, 1997; UNEP, 2004b). Adequate feed points should be selected according to the characteristics of the waste, including its physical, chemical and toxicological properties. For example, combustible toxic compounds found in some hazardous waste, such as halogenated organic substances, need to be completely destroyed through proper temperature and residence time. In preheater/precalciner kilns, hazardous waste should generally be fed through either the main or the secondary burners. Halides (e.g. chlorides, bromides and fluorides) have an impact on the quality of the cement so their presence must be limited. Chlorine can be found in all raw materials used in cement manufacture, so total halogen (e.g. chlorine, bromine and fluorine) levels in the hazardous waste can be critical (European Commission, 2013a). However, if they are blended down sufficiently, cement kilns can treat highly chlorinated hazardous waste. Cement kilns can also treat wastes containing or contaminated with PFASs, including PFOS, PFOA, and PFHxS with introduction to the main burner and the calciner (Cement Australia, 2017, Cement Australia 2018) on the basis of research showing that an excess of calcium can catalyze PFAS destruction and capture the fluorine within normal cement kiln process parameters (Wang et al., 2011; Wang et al., 2015; Riedel et al., 2021).

235. The potential feed points for supplying waste would be:

- (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, 2004b).

236. The guidance on BAT/BEP developed by the Stockholm Convention relevant to Article 5 and Annex C on cement kiln firing hazardous waste should be used and applied to this technology (UNEP, 2007). Some countries have established legislation on BAT (European Commission, 2019b). In some EU countries, limit values for concentrations of PCBs in waste have been set for cement kilns (10, 50 and 100 mg/kg) (European Commission, 2013a).

237. *Efficiency:* DREs greater than 99.99998% have been reported for PCBs in several countries. A facility should demonstrate its capability to destroy (through combustion) or remove (through settling in ductwork or air pollution control devices) at least 99.9999% of targeted POPs (Karstensen et al., 2009). Reported DE and DRE values for DDT are in the range of 99.9335-99.9998% and 99.9984-99.9999%, respectively (Yan et al., 2014) and DRE greater than 99.9999 per cent (Li et al., 2012). A study reported DREs of 99.9997% and 99.9998% for decaBDE in contaminated soil treated in a cement kiln (Yang et al. 2012). Another study reported a DE of 82.6% for PCDD/F in fly ash from municipal solid waste incinerator treated in a cement kiln (Yang et al., 2018). Processing municipal solid waste incinerator fly ash in cement kilns can lead to even lower DE (Liu et al., 2016b). The results of a trial reported a DRE for PFOS, PFOA, and PFHxS of 99.999% (Cement Australia, 2018). Process operating constraints may become significant when certain compounds, for example

⁴⁶ 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; STAP, 2011; Stobiecki et al., 2001, UNEP, 1998; and US EPA, 2010. In addition, information on BAT and BEP with respect to cement kilns firing hazardous waste is available from the European Commission, 2019c; and OECD, 2020.

circulating volatile elements such as chlorine, sulfur or alkalis, are present in excessive quantities (Karstensen, 2008).

238. *Waste types:* Virtually any organic compound can be destroyed at the minimum temperature of 1,400 °C of a properly operating cement kiln (UNEP, 2002a). Cement kilns are capable of treating both liquid and solid wastes (CMPS&F – Environment Australia, 1997; Rahuman et al., 2000; and Karstensen et al., 2006). In addition, upgrading and purification of automotive shredder residue is required before it is used as fuel substitute in high percentages in a cement kiln (Vermeulen et al., 2011). Cement kilns are also capable of treating wastes containing or contaminated with PFASs, including PFOS and PFOA, and PFHxS (Cement Australia, 2018; Queensland Department of Environment and Science, 2021).

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

- (a) Thermal desorption of solid wastes;
- (b) Homogenization of solid and liquid wastes through drying, shredding, blending, mixing and grinding;
- (c) Volume reduction;
- (d) Blending.

240. *Emissions and residues:* Cement kiln co-incineration of hazardous wastes is listed as an industrial source category that has the potential for comparatively high formation and release of the unintentionally formed POPs listed in Annex C to the Stockholm Convention. Emissions may include, *inter alia*, nitrogen oxides, carbon monoxide, sulfur dioxide and other oxides of sulfur, metals and their compounds, hydrogen chloride, hydrogen fluoride, ammonia, PCDDs, PCDFs, benzene, toluene, xylene, polycyclic aromatic hydrocarbons, chlorobenzenes and PCBs (UNEP, 2004b) and PCN (Liu et al., 2016a, German Federal Environment Agency, 2015) and PBDD/Fs (Du Bing et al. 2011). It should be noted that cement kilns can comply with PCDD and PCDF air emission levels below 0.1 ng TEQ/Nm³ although waste with high chlorine levels should be fed together with other wastes to avoid adversely affecting emission levels, particularly in wet and (long) dry kilns.⁴⁷ Recycling cement kiln dust back into the production process results in elevated concentrations of PCDD/Fs in the flue gases of cement plants (Zhan et al., 2018). For wastes containing or contaminated with PFASs treated with an excess of calcium in a cement kiln trial, the total fluoride in gaseous emissions (as HF) in the main stack at 0.045 mg/Nm³ was not substantially different to baseline levels at 0.031 mg/Nm³ (Cement Australia, 2018). Residues include cement kiln dust captured by the air pollution control systems.

241. *Release control and post-treatment:* Process gases must be treated to remove cement kiln dust and organic compounds, sulfur dioxide and nitrogen oxide; they must also be heated so that the formation of PCDDs and PCDFs is minimized. Treatments include the use of preheaters, electrostatic precipitators, fabric filters and activated carbon filters (CMPS&F – Environment Australia, 1997; Karstensen et al., 2006; UNEP, 2004b). 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.

242. Periodic measurements of PCDD/F emissions from cement kilns co-incinerating waste should be performed and a frequency appropriate to the raw materials and fuels that are used in the process should be applied (European Commission, 2013a; European Commission, 2013b).

243. *Energy requirements:* For new facilities and major upgrades using dry process kiln with multistage preheating and precalcination, the BAT-associated energy consumption is 2,900-3,200 MJ/tonne clinker under normal (excluding, e.g. start-ups and shutdowns) and optimised operational conditions (not applying to facilities producing special cement or white cement clinker that require significantly higher process temperatures due to product specifications). The production capacity has an influence on the energy demand, with higher capacities providing energy savings and smaller capacities requiring more energy. Energy consumption also depends on the number of cyclone preheater stages, with more cyclone preheater stages leading to lower energy consumption of the kiln process. The appropriate number of cyclone preheater stages is mainly determined by the moisture content of raw materials (European Commission, 2013a).

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

⁴⁷ In exceptional cases, emission levels from cement kilns co-incinerating wastes has been reported at 136 ng TEQ/m³ (UNEP, 2007).

245. *Portability*: Cement kilns are available only in fixed configurations.
246. *Health and safety*: Treatment of wastes in cement kilns can be regarded as relatively safe provided that kilns are properly designed and operated.
247. *Capacity*: Cement kilns that co-incinerate waste as fuel must normally not meet more than 40 per cent of their heat requirements with hazardous waste. It has been noted, however, that cement kilns with high throughput can potentially treat significant quantities of waste (CMPS&F – Environment Australia, 1997).
248. *State of commercialization*: Cement kilns in the United States, some European countries and a number of developing countries have been and are used to treat wastes contaminated with POPs (World Business Council, 2004: Formation and Release of POPs in the Cement Industry; Karstensen, 2006). A cement kiln licensed to treat waste containing or contaminated with PFASs, including PFOS, PFOA, and PFHxS is operating in Australia (Queensland Department of Environment and Science, 2021).
249. *Additional information*: See the UNEP Technical guidelines on the environmentally sound co-processing of hazardous wastes in cement kilns (UNEP, 2011) and the Commission implementing decision 2013/163/EU establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU on industrial emissions for the production of cement, lime and magnesium oxide (European Commission, 2013b).

(f) Gas-phase chemical reduction (GPCR)⁴⁸

250. *Process description*: The GPCR process⁴⁹ 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, hydrogen chloride (if the waste is chlorinated), and minor amounts of low molecular weight hydrocarbons (benzene and ethylene). The hydrochloric acid is neutralized through the addition of caustic soda during the initial cooling of the process gas, or can be taken off in acid form for reuse. The GPCR technology can be broken down into three basic unit operations: a front-end system (where the contaminants are transformed into a suitable form for destruction in the reactor), a reactor (which reduces the contaminants, at this stage in gas phase, using hydrogen and steam), and a gas scrubbing and compression system.
251. *Efficiency*: DEs of 99.9999 per cent have been reported for DDT, HCB, PCBs, PCDDs and PCDFs (CMPS&F – Environment Australia, 1997; Kümmling et al., 2001; Rahuman et al., 2000; UNEP, 2004a; and Vijgen, 2002). DEs of more than 99.999% have been reported for PCBs, 99.999% for PCDD contained in waste oils containing PCBs (UNEP, 2000a), as well as DE above 99.9999 % for HCB and chlorobenzenes (Kümmling et al., 2002, Arnold, 2003).
252. *Waste types*: GPCR is expected to be able to treat all POP wastes, including aqueous and oily liquids, soils, sediments, sludges, transformers and capacitors (CMPS&F – Environment Australia, 1997; UNEP, 2004a; Vijgen, 2002; US EPA, 2010).
253. *Pre-treatment*: Contaminants must be in gaseous form for a GPCR reactor to reduce them. While liquid wastes can be preheated and injected directly into the reactor on a continuous basis, contaminants on solids must first be volatilized from the solids. Depending on the waste type, one of the following three pre-treatment units is currently used to volatilize wastes prior to treatment in a GPCR reactor:
- (a) Thermal reduction batch processors (TRBPs) for bulk solids, including those in drums;
 - (b) Toroidal bed reactors for contaminated soils and sediments, but also adapted for liquids;
 - (c) Liquid waste pre-heater systems (LWPSs) for liquids (CMPS&F – Environment Australia, 1997; Kümmling et al., 2001; UNEP, 2001; UNEP, 2004a).
254. 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 (CMPS&F – Environment Australia, 1997).
255. *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

⁴⁸ Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Danish Environmental Protection Agency, 2004; Kümmling et al., 2001; Rahuman et al., 2000; Ray, 2001; UNEP, 2001; UNEP, 2004a; US EPA, 2010; and Vijgen, 2002.

⁴⁹ The process can also be called hydrogenation (European Commission, 2017a).

residues will also be generated from solid waste inputs (UNEP, 2004a; Vijgen, 2002). Since the GPCR process takes place in a reducing atmosphere, the possibility of PCDD and PCDF formation is considered limited (CMPS&F – Environment Australia, 1997; and Rahuman et al., 2000). No ash is produced. Emissions of PCDD/PCDF from the gas phase chemical reduction process to all media were lower than those from base catalysed decomposition (Danish Environmental Protection Agency (2004).

256. *Release control and post-treatment:* Gases leaving the reactor are scrubbed to remove water, heat, acid and carbon dioxide (Kümmling et al., 2001; CMPS&F – Environment Australia, 1997; Rahuman et al., 2000). Scrubber residue and particulate will require disposal off site (Rahuman et al., 2000; Vijgen, 2002). Solid residues generated from solid waste inputs should be suitable for disposal in a landfill (UNEP, 2004a).

257. *Energy requirements:* Methane produced during the GPCR process can provide much of the fuel needed in the process (CMPS&F – Environment Australia, 1997; Rahuman et al., 2000; UNEP, 2001; UNEP, 2004a; Vijgen, 2002). 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 (CMPS&F – Environment Australia, 1997).

258. *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 (CMPS&F – Environment Australia, 1997; Rahuman et al., 2000; UNEP, 2004a; and Vijgen, 2002). The hydrogen production unit was plagued, however, by reliability problems in the past (CMPS&F – Environment Australia, 1997). Other material requirements include caustic for the acid scrubber (UNEP, 2004a).

259. *Portability:* GPCR is available in fixed and transportable configurations (UNEP, 2001; UNEP, 2004a; and Vijgen, 2002).

260. *Health and safety:* Use of hydrogen gas under pressure requires suitable controls and safeguards to ensure that explosive air-hydrogen mixtures are not formed (CMPS&F – Environment Australia, 1997). Operating experience gained to date has indicated that the GPCR process can be undertaken safely (CMPS&F – Environment Australia, 1997; UNEP, 2004a). GPCR is used to treat sewage sludge by converting the waste into clean water and a clean hydrogen enriched methane gas while chemically destroying all pathogens and pharmaceuticals and recovering phosphorous. There are no fugitive methane emissions in the process.

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

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

(b) Toroidal bed reactors have a capacity of up to 5,000 tonnes of soils and sediments per month, although these pre-treatment units are still in the development stage; and

(c) LWPSs have a capacity of three litres per minute (UNEP, 2004a; Vijgen, 2002).

262. *Other practical issues:* Contaminants such as sulfur and arsenic were found to inhibit treatment in earlier development stages, although it is unclear whether this problem persists (CMPS&F – Environment Australia, 1997).

263. *State of commercialization:* Commercial-scale GPCR facilities have operated in Canada and Australia. The GPCR facility in Kwinana, Western Australia operated for more than five years until 2000 by which time it has treated most of the PCB stockpiles for that state and a significant quantity of POP wastes from other Australian states (CMPS&F – Environment Australia, 1997; Kümmling et al., 2001; Ray, 2001; UNEP, 2004a and Vijgen, 2002). In the United States, there is a plan to build a GPCR synthetic diesel facility in Fauquier County, Virginia, with a daily processing capacity of 200 Mg.

(g) Hazardous waste incineration⁵⁰

264. *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

⁵⁰ Additional information is available from Danish Environmental Protection Agency, 2004; US Federal Remediation Technology Roundtable (FRTR), 2002; Rahuman et al., 2000; STAP, 2011; UNEP, XXXX; UNEP, 1998; 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 UNEP, 2015.

temperature greater than 850 °C or, if the waste contains more than 1 per cent of halogenated organic substances expressed as chlorine, to a temperature greater than 1,100 °C, with a residence time greater than two seconds under conditions that ensure appropriate mixing. Dedicated hazardous waste incinerators are available in a number of configurations, including rotary kiln incinerators and static ovens (for liquids with low contamination). High-efficiency boilers and lightweight aggregate kilns are also used for the co-incineration of hazardous wastes.

265. The guidance on BAT/BEP developed by the Stockholm Convention relevant to Article 5 and Annex C for waste incinerator should be used and applied to this technology (UNEP, 2007). Some countries have established guidance on BAT (European Commission, 2019c).

266. *Efficiency:* DREs greater than 99.9999 per cent have been reported for treatment of PCBs, PCDDs and PCDFs, chlordane and HCB (FRTR, 2002; Rahuman et al., 2000; UNEP, 1998; UNEP, 2001). DEs greater than 99.999 and DREs greater than 99.9999 per cent have been reported for aldrin, endrin, HCH, DDT and PFOS (Ministry of the Environment of Japan, 2004 and 2013b). DE and DRE were reported for PCN at 99.9974 and 99.9995 per cent, respectively (Yamamoto et al., 2016). State-of-the-art incineration reaches destruction rates of more than 99.9 per cent for HCB and PCP and between 99.32 and 99.96 for PCNs (German Federal Environment Agency, 2015). For the treatment of BFR-containing products, DE greater than 99.999% and 99.9999% have been reported for XPS containing HBCD and WEEE plastics containing decaBDE, respectively (Kajiwara et al., 2017; 2021). DE of greater than 99.9999% is reported for HCB co-incineration test with the emission of PCDDs/PCDFs being comparable to the baseline test (Kajiwara et al. 2019).

267. The efficiency of incineration to destroy PFAS compounds and the tendency for formation of fluorinated or mixed halogenated organic compounds is not well understood. It is likely that fluorinated organic compounds require higher temperatures to achieve 99.99% destruction in 1 second residence time than their chlorinated counterparts. Incomplete destruction of PFASs can result in the formation of smaller PFAS chemicals and breakdown products (US EPA, 2020a).

268. *Waste types:* Hazardous waste incinerators are capable of treating wastes consisting of, containing or contaminated with POPs (UNEP, 2002a); Incinerators can be designed to accept wastes in any concentration or physical form, i.e., as gases, liquids, solids, sludges or slurries (UNEP, 2022b).

269. *Pre-treatment:* Depending upon the configuration, pre-treatment requirements may include blending and size reduction of wastes (UNEP, 2022d; UNEP, 1998; and UNEP, 2004b).

270. For polystyrene foam (EPS and XPS) wastes containing HBCD, a series of steps can be applied to separate HBCD from polystyrene and subsequently destroy HBCD in hazardous waste incinerators⁵¹. The relevant pre-treatments operations include volume reduction, size reduction, dissolution, sedimentation, and distillation. In the case of XPS waste containing HBCD and which may also contain ozone depleting substances controlled by the Montreal Protocol on Substances That Deplete the Ozone Layer⁵², measures should be taken to prevent the release of ODS to the environment during these pre-treatment operations.

271. *Emissions and residues:* Emissions include carbon monoxide, carbon dioxide, HCB, hydrogen chloride, particulates, PCDDs, PCDFs and PCBs, heavy metals and water vapour (UNEP, 2022d; UNEP, 1998; and UNEP, 2004b). Incinerators applying BAT that, *inter alia*, are designed to operate at high temperatures, to prevent the re-formation of PCDDs and PCDFs and to transfer PCDD and PCDF from gaseous emissions to fly ash (e.g., with the use of activated carbon filters), have led to very low PCDD and PCDF emissions to air and discharges to water (UNEP, 2007; European Commission 2019c). In residues, PCDDs and PCDFs are mainly found in fly ash and salt, and to some extent in bottom ash and scrubber water sludge. Levels of PCDD/Fs in fly ash from hazardous waste incinerators can be in the range from 0.0002 to 124.5 ng TEQ/g (European Commission, 2005; Petrlik and Ryder, 2005; Cobo et al., 2009; Noma et al., 2006).

272. Generation of low molecular weight PFASs (including POP-PFASs) in destruction of fluoropolymers (polytetrafluoroethylene (PTFE)) under typical waste incineration conditions was studied at the BRENDA pilot plant at Karlsruhe Institute of Technology (KIT) (Aleksandrov et al., 2019). No statistically significant evidence was found that PFOS, PFOA, or PFHxS was created during the incineration of PTFE. In an incineration residuals study of 27 Swedish waste incineration plants, PFAS were found in bottom ash in 9 plants sampled, in fly ash of 15 plants and in condensate water of 13 plants. The concentration of PFOS in fly ash from two incineration facilities was 3.74 and 3.44 µg/kg, and levels of PFASs in the pooled fly ash samples from 15 furnaces were in

⁵¹ <http://polystyreneloop.org/>.

⁵² <https://ozone.unep.org/>.

concentrations between 0.18 to 37.71 µg/kg. PFAS concentrations in bottom ash were 0.22-12.76 µg/kg and in condensate water 0.28-182.95 ng/L (Strandberg et al., 2021). It is not known which results represent hazardous waste incineration facilities.

273. *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 (sulfur and nitrogen oxides, heavy metals and organic micro pollutants such as PAHs, like carbon monoxide, are being used as an indicator of combustion efficiency). This can be achieved through a combination of types of post-treatments, including the use of cyclones and multi-cyclones, electrostatic filters, static bed filters, scrubbers, selective catalytic reduction, rapid quenching systems and carbon adsorption (UNEP, 2004b). Depending upon their characteristics, bottom and fly ashes may require disposal within a specially engineered landfill or permanent storage in underground mines and formations (United States Army Corps of Engineers, 2003). Perfluorinated chemicals are not routinely measured in waste incineration exhaust gases, and little information is available on their presence in exhaust gases from incineration of PFAS containing waste (Stoiber et al., 2020; US EPA, 2020a).

274. The channeled emissions to the air of PCDD/Fs and dioxin-like PCBs from incineration of waste should be monitored with at least the frequency of once every six months for short-term sampling and of once every month for long-term sampling if the emission levels are not proven to be sufficiently stable (European Commission, 2019b; European Commission, 2019c).

275. In some cases, the channeled emissions to the air of PBDD/Fs may need to be monitored. For example, in the EU, for PBDD/Fs, a monitoring frequency of at least once every six months is required, but only in case the waste contains brominated flame retardants or when there is continuous injection of bromine to reduce mercury emissions to air (European Commission, 2019b; European Commission, 2019c).

276. *Energy requirements:* The amount of combustion fuel required will depend upon the composition and calorific value of the waste and also upon the flue gas treatment technologies applied.

277. *Material requirements:* Material requirements include cooling water and lime or another suitable material for removal of acid gases and other pollutants like active carbon.

278. *Portability:* Hazardous waste incinerators are available in both mobile and fixed units.

279. *Health and safety:* Health and safety hazards include those associated with operations involving high temperatures (United States Army Corps of Engineers, 2003).

280. *Capacity:* Hazardous waste incinerators can treat between 30,000 and 100,000 tonnes of waste per year (UNEP, 2004b).

281. *Other practical issues:* None to report at this time.

282. *State of commercialization:* There is a long history of experience with hazardous waste incineration (UNEP, 2001).

(h) Plasma Arc⁵³

283. *Process description:* The waste, as a liquid or gas, is injected directly into the plasma and is rapidly (<1 ms) heat up to about 3,100 °C and pyrolysed for about 20 ms in the water-cooled reaction chamber (flight tube). 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 (CMPS&F – Environment Australia, 1997). The plasma arc system requires a mono-nitrogen oxides (NO_x) abatement device, as important amounts of NO_x are produced by the high temperature flame.

284. The guidance on BAT/BEP developed by the Stockholm Convention relevant to Article 5 and Annex C should be used and applied to this technology (UNEP, 2007).

285. *Efficiency:* Bench-scale tests with oils containing 60 per cent PCBs have achieved DREs ranging from 99.9999-99.999999 per cent (Rahuman et al., 2000; UNEP, 2004a). A DE of 99.9999 per cent is achievable for most pesticide POPs, including chlordane, chlordecone, DDT, endosulfan and heptachlor.

286. *Waste types:* Plasma arc system facilities have been used to treat a wide range of PCBs, pesticide POPs, halons and chlorofluorohydrocarbons. Waste types to be treated must be liquid or gas,

⁵³ Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Rahuman et al., 2000; Ray, 2001; STAP, 2011; UNEP, 1998; UNEP, 2000a; UNEP, 2001 and UNEP, 2004a.

or solid if the waste is contained in a fine slurry that 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 (CMPS&F – Environment Australia, 1997; UNEP, 2004a).

287. *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 (CMPS&F – Environment Australia, 1997; UNEP, 2004a).

288. *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. Traces of PCDD and PCDF have been detected in effluent gas from plasma arc systems. These traces are at a concentration of less than 0.01 ng TEQ/Nm³. POP concentrations in solid residues are unknown (UNEP, 2004b).

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

290. *Energy requirements*: A 150 kW plasma arc system unit requires 1,000–3,000 kWh of electricity per tonne of waste treated (CMPS&F – Environment Australia, 1997).

291. *Material requirements*: Currently, there is little information available regarding material requirements. It has been noted, however, that this process requires argon gas, oxygen gas, caustic and cooling water (CMPS&F – Environment Australia, 1997; UNEP, 2004a).

292. *Portability*: Plasma arc systems are available in both portable and fixed units (UNEP, 2004a).

293. *Health and safety*: Since the plasma arc system process has a low throughput, there is a low risk associated with the release of partially treated wastes following process failures (CMPS&F – Environment Australia, 1997; UNEP, 2004a). Currently, there is little additional information available regarding health and safety.

294. *Capacity*: A 150 kW plasma arc system unit can process 1–3 Mg of waste per day (CMPS&F – Environment Australia, 1997; and UNEP, 2004a).

295. *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 residues. For example, arsenicals in pesticide waste exported from Pacific islands for disposal in Australia using the plasma arc system process have presented problems.

296. *State of commercialization*: There are two plasma facilities operating in Australia: one in Laverton, Victoria as part of an agricultural chemical plant and one in Narangba, Queensland.

(i) Plasma Melting Decomposition Method

297. *Process description*: The plasma melting decomposition method (PMD) is a thermal destruction method for solid waste containing or contaminated with PCBs. Solid waste containing or contaminated with PCBs is canned directly into containers, such as drums or pails, without shredding or disassembling. In a plasma furnace, a plasma torch generates high temperature plasma gas (air) so that the furnace temperature is maintained to melt the waste together with the container itself. All the organic substances, including PCBs, are decomposed into CO₂, H₂O and HCl under the high temperature conditions of the plasma furnace, and inorganic materials, including metals, are oxidized to become molten slag. The plasma furnace temperatures exceed 1,400°C (Tagashira et al., 2006).

298. *Efficiency*: In Japan, a pilot PMD facility was tested for PCB treatment in 2006. The result showed DEs ranging from 99.9999454–99.9999997 per cent and DREs ranging from 99.9999763–99.9999998 per cent (Tagashira et al., 2006).

299. *Waste types*: In commercial scale facilities in Japan, solid waste containing or contaminated with PCBs, such as fluorescent light ballasts, sludge, carbonless paper and secondary contaminants, can be treated using PMD (JESCO, 2013).

300. *Pre-treatment*: Japan's commercial-scale facilities uses containers such as drums and pails in which PCB-contaminated waste is mixed with basicity-controlling agents like limestone or silica sand, as needed, and pushed into the plasma furnace (JESCO, 2009a; JESCO, 2013).

301. *Emissions and residues*: The JESCO plasma melting treatment facility can comply with dioxins air emission levels below 0.1 ng TEQ/Nm³ (JESCO, 2009). Air emission levels of dioxins were 0.0000043–0.068 ng TEQ/Nm³ in a pilot scale facility (Tagashira et al., 2006). Together with an

enhanced gas treatment system, dioxin emission levels can be controlled within a range of 0.00001 - 0.001 ng TEQ/Nm³ (Tagashira et al., 2007).

302. *Release and control and post-treatment:* In Japan, as exhaust gas pollution control, two-stage bag filters with lime and pulverized activated carbon injection remove dust, acid gas such as HCl and SO_x and dioxins, while catalyst towers with NH₃ gas injection remove NO_x. Activated carbon is installed at the last stage (Tagashira et al., 2006).

303. *Material requirements:* PMD is reported to require lime and pulverized activated carbon supply (Tagashira et al., 2006). To improve molten slag fluidity, basicity-controlling agents such as silica sand or limestone may also be required.

304. *Portability:* PMD is available only in fixed units (JESCO, 2009a).

305. *Capacity:* In Japan, it has been demonstrated that the two JESCO plasma melting treatment facilities operating there are capable of treating 10.4 tonnes and 12.2 tonnes of PCB-containing waste per day, respectively (JESCO, 2009a; JESCO, 2013).

306. *State of commercialization:* In Japan, the JESCO plasma melting treatment facility in Kitakyushu has used PMD technology treatment of 10.4 tonnes of PCB waste per day on a commercial scale since July 2009 (JESCO, 2009a) and the same type of facility in Hokkaido having the capacity to treat 12.2 tonnes of PCB waste per day has also been in commercial operations since 2013 (JESCO, 2013).

307. *Additional information:* See the following website for further information: <http://www.jesconet.co.jp/eg/pdf/plasma.pdf>.

(j) Supercritical water oxidation (SCWO) and subcritical water oxidation⁵⁴

308. *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.

309. *Efficiency:* DEs greater than 99.999 per cent and DREs greater than 99.9999 per cent have been reported for chlordane, DDT and PCBs for SCWO (Ministry of the Environment of Japan, 2004). DEs greater than 99.999999 per cent 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 (CMPS&F – Environment Australia, 1997; Rahuman et al., 2000; Vijgen, 2002). SCWO has been shown to be effective in the treatment of toxic chlorinated chemicals such as PCBs, pesticides and flame retardants (Marrone and Hong, 2007). Overall, SCWO usually has a DE greater than 99.99 per cent for a wide range of organic compounds (Marrone and Hong, 2007).

310. *Waste types:* SCWO and subcritical water oxidation are thought to be applicable to all POPs (UNEP, 2004a). 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 by weight (CMPS&F – Environment Australia, 1997; Rahuman et al., 2000; Vijgen, 2002). Supercritical and subcritical fluids have been showed to decompose HIPS plastics containing decaBDE. The main reaction products were oils containing ethylbenzene. The bromine from the flame retardant was removed into the aqueous phase (Onwudili & Williams, 2009; Goto, 2016).

311. *Pre-treatment:* Concentrated wastes may have to be diluted prior to SCWO treatment in order to reduce their organic content to below 20 per cent by weight. If solids are present, they must be reduced to less than 200 µm in diameter. Other processing options include addition of fuel to low concentration wastes, co-processing of dilute and concentrated wastes and partial sludge dewatering, among others. In the case of subcritical water oxidation, the dilution of wastes is not necessary.

312. *Emissions and residues:* Under operating conditions above the critical range of 500 °C–650 °C and 25 MPa with reactor residence times of under one minute for complete destruction PCDD/PCDF, NO_x and other toxic by-products are not formed in SCWO (Marrone, 2013). However, during laboratory-scale PCB destruction, it was shown that the SCWO technology has the potential to form high concentrations of PCDFs during PCB degradation in experiments below 450 °C (Weber, 2004a). It has been reported that emissions contain no oxides of nitrogen or acid gases such as hydrogen

⁵⁴ Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Rahuman et al., 2000; UNEP, 2001; and UNEP, 2004a.

chloride or oxides of sulfur and that process residues consist of water and solids if the waste contains inorganic salts or organic compounds with halogens, sulfur or phosphorus (CMPS&F – Environment Australia, 1997). Limited information has been reported regarding potential concentrations of undestroyed chemicals (CMPS&F – Environment Australia, 1997; UNEP, 2004a). The process is designed so that emissions and residues can be captured for reprocessing if needed (UNEP, 2004a).

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

314. *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 (Rahuman et al., 2000).

315. *Material requirements:* SCWO and subcritical water oxidation reaction vessels must be constructed of materials capable of resisting corrosion caused by halogen ions. Material corrosion can be severe at the temperatures and pressures used in the SCWO and subcritical water oxidation processes. 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 (Vijgen, 2002).

316. *Portability:* The SCWO and subcritical water oxidation units are predominantly used in fixed configurations (UNEP, 2004a; Vijgen, 2004). However, General Atomics Electromagnetic Systems (GA-EMS) have developed an industrial SCWO system (iSCWO) which are transportable and housed in shipping containers for on-site treatment of hazardous wastes containing POPs. Transportable iSCWO is currently used in Kyrgyzstan and Tajikistan to destroy the DDT content in 5000 tonnes of wastes containing DDT.⁵⁵

317. *Health and safety:* The high temperatures and pressures used in SCWO and subcritical water oxidation processes require special safety precautions (CMPS&F – Environment Australia, 1997).

318. *Capacity:* Current SCWO demonstration units are capable of treating 0.5 t/h, while full-scale units can be designed to treat up to 10 t/h (Marrone et al., 2013).

319. *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 (CMPS&F – Environment Australia, 1997).

320. *State of commercialization:* A full-scale SWCO commercial facility with the capacity to treat 2 tonnes of waste per day was installed in 2005 and is in operation in Japan (JESCO, 2009d). In addition, the SCWO process has been approved for full-scale development and use in the chemical-weapon destruction programme of the United States and for spent catalyst in UK (Veriansyah and Kim, 2007). There are plants in commercial operation also in France and Korea (Marrone et al., 2013), as well as in China (Li and Wang, 2019) and the Russian Federation⁵⁶.

(k) Thermal and metallurgical production of metals

321. *Process description:* The metal production processes described below are primarily designed for the recovery of iron and non-ferrous metals (NFM), e.g., aluminium, zinc, lead, and nickel from ore concentrates as well as from secondary raw materials (intermediates, wastes, scrap). However, due to their nature, the processes are in some cases also used on a commercial basis for the destruction of the POP content of appropriate wastes (see paragraph 324). A general description of some of the following processes may be found in the European BAT reference documents for Iron and Steel Production (European Commission, 2013b) and NFM industries (European Commission, 2017b):

(a) Processes that are relevant for the destruction of the POP content in iron-containing wastes use certain types of blast furnaces, shaft furnaces or hearth furnaces. All these processes operate under reducing atmospheres at high temperatures (1,200 °C–1,450 °C). The reducing atmospheres and high temperatures destroy PCDDs and PCDFs contained in the wastes and avoid de novo synthesis. The blast furnace and 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 gas 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

⁵⁵ GEF Project ID 9421: <https://www.thegef.org/project/demonstration-non-thermal-treatment-ddt-wastes-central-asia>.

⁵⁶ <http://www.russoshki.ru/selhoz.html>.

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 that are relevant for the destruction of the POP content in wastes containing NFM s are the Waelz rotary kiln process and bath melting processes using vertical or horizontal furnaces. In the Waelz process, zinc-containing steel mill dusts, sludges, filter cakes, etc. are pelletized and smelted together with a reductant. The normal operating temperature inside a Waelz kiln is about 1200–1400 °C. Inside the kiln, solid materials are first dried and then heated up by the countercurrent flow of hot gas and contact with the refractory-lined walls. Depending on the inclination, length and rotation speed, the material has an average residence time of between 4 and 6 hours in the kiln. In the strongly reducing atmosphere of the solid bed, zinc, lead and other metals are reduced (European Commission, 2017b). At a temperature of 1,200 °C, the zinc volatilizes and is oxidized to “Waelz Oxide”. The SDHL⁵⁷ process is a further development of the conventional Waelz process using the basic slag system with the addition of a reoxidation step for iron at the end to reduce the energy consumption and to improve the zinc yield and throughput. It can be retrofitted to existing Waelz plants. In the vertical bath furnace process, copper-containing residues are used as a catalyst and 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 zone and a reducing zone with temperatures of between 1,000 °C and 1,200 °C. The process gas (sulfur dioxide concentration above 10 per cent) is used for sulfuric acid production after heat recovery and de-dusting. The dust from the process is recycled after cadmium leaching.

322. The guidance on BAT/BEP developed by the Stockholm Convention relevant to Article 5 and Annex C for thermal processes in the metallurgical industry should be used and applied to this technology (UNEP, 2007)

323. *Efficiency:* There are few data on DEs in metal production processes. A spot test from 2010 in a copper smelter (bath melting) using printed circuit board as input material indicated a destruction efficiency for the PBDEs above 99.99 % (European Commission, 2011).

324. *Waste types:* The processes described in paragraph 321 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;

(c) Waste electrical and electronic equipment that may contain POP-BDEs;

(d) Automotive shredder residue that may contain POP-BDEs (Oeko Institut, 2018).

325. *Pre-treatment:* Iron-containing materials recycled by the conventional blast furnace process require pre-treatment in an agglomeration facility. For the shaft furnace (“Oxycup” furnace) process the iron-containing waste is briquetted. Briquetting is a cold process in which a binder and water are 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 in some special cases the fine solids may have to be pelletized. Pelletizing involves 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 s.

326. *Emissions and residues:* In iron and NFM production, PCDDs and PCDFs may be emitted during the process itself or downstream in the flue gas treatment system. POP-BDEs, PBDD/PBDF and PXDD/PXDF may be released to a certain extent which depends on the DE of respective facility (UNEP, 2015e). Application of BAT should, however, prevent or at least minimize such emissions. A reduction of the PCDD/F concentration in the raw gas to < 0.1 ng/Nm³ can be obtained using the SDHL process. The SDHL process can also reach PCDD/F values below 0.01 ng/Nm³. Organic compounds can be reduced by post-combustion systems, if required (European Commission, 2017b). When the processes described in paragraph 321 above are used for the destruction of POP content in wastes, appropriate release control and post-treatment techniques are required (see paragraph 328 below). For iron metals, emissions can occur from pre-treatment in an agglomeration facility and also

⁵⁷ SDHL is an efficiency modification of the Waelz process named after the inventors Saage, Hasche, Dittrich and Langbein.

in the off-gas from melting furnaces. Residues from de-dusting systems are mainly used in the NFM industry. The off-gas of multi-hearth furnaces is de-dusted by a cyclone, underlies a post-combustion, and is quenched and cleaned with the addition of adsorbent and the use of a bag filter. The off-gas of melting furnaces also underlies post-combustion and is quenched before it is mixed up with the off-gas of multi-hearth furnaces for the joint adsorbance step. For NFMs, residues include filter dusts and sludges from wastewater treatment.

327. Waelz plants processing electric arc furnace dust may have high PCDD/PCDF emissions, especially in acid operating mode (Chi et al., 2006; Hung et al., 2012). The releases are dominated by the formation of PCDD/PCDF in the process, as PCDD/F concentrations in the feed materials are almost completely destroyed thermally in the basic operating mode (Mager et al., 2003). In some dusts from Waelz kilns treating electric arc furnace dust, PCDD/F values of 100 ng/Nm³ are measured without specific techniques (European Commission, 2017b).

328. *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 that consists mainly of metals or metal oxides as well as sulfur dioxide when smelting sulphidic materials. In the ferrous metals industry, waste gases from agglomeration facilities are treated by an electrostatic precipitator followed by further flue gas treatment, e.g., with the use of 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 the addition of adsorbent followed by the use of a bag filter. The off-gases from melting furnaces also require post-combustion and quenching and are then combined with the off-gas stream from multi-hearth furnaces for further treatment with the addition of adsorbent followed by the use of a bag filter. In NFM production, suitable treatment techniques include the use of, *inter alia*, fabric filters, electrostatic precipitators or scrubbers, sulfuric acid plants, and adsorption techniques with activated carbon.

329. *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.

330. *Material requirements:* For the production of metals, raw materials (ores, concentrates or secondary material) are used together with 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.

331. *Portability:* Metal smelters are large and fixed installations.

332. *Health and safety:* The treatment of wastes within thermal processes can be regarded as safe if properly designed and operated.

333. *Capacity:* The 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.

334. *Other practical issues:* None.

335. *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 (<http://www.dk-duisburg.de>), where a shaft furnace ("Oxycup" furnace) has been in operation since 2003 (<http://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 (<https://lucchinirs.com/>). The Waelz rotary kiln process is well-established and is covered by BAT that are in operation at different sites in Europe (<http://www.befesa-steel.com>). The vertical bath melting process is in operation in Germany (<http://www.aurubis.com>), as is the horizontal bath melting process (www.berzelius.de).

3. Other disposal methods when destruction or irreversible transformation is not the environmentally preferable option

336. When destruction or irreversible transformation is not the environmentally preferable option for wastes with a POP content at or above the low POP content referred to in subsection A of section III above, countries could allow such wastes to be disposed of in an environmentally sound manner through methods other than those referred to in subsection IV.G.2.

337. Wastes containing or contaminated with POPs where such other disposal methods may be considered include, but are not limited to:

- (a) Wastes from power stations and other combustion facilities (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. Such wastes include bottom ash, slag, salt slags, fly ash, boiler dust, flue gas dust and 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) Vitrified wastes and waste from vitrification, including fly ash and other flue gas treatment wastes and non-vitrified solid phase wastes.

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

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

(a) Specially engineered landfill

340. Any landfilling of waste consisting of, containing or contaminated with POPs in specially engineered landfills should be carried out in conformity with the *Technical guidelines on the environmentally sound disposal of hazardous wastes and other wastes in specially engineered landfill* (D5) (UNEP, 2022c). Accordingly, such waste should, where necessary, be pre-treated, e.g. in a suitable solidification process, before being accepted by an engineered landfill in order to minimize the potential of the POP content to enter the environment.

341. Chemicals, including POPs, found in leachate and discharged into the receiving environment can have an impact on the environment and human health. Landfill leachate on-site treatment technologies should be in place to reduce and prevent leachate contaminated with POPs from entering the environment.

342. 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 waste;
- (c) Empty containers, unless they are crushed, shredded or similarly reduced in volume;
- (d) Explosives, flammable solids, self-heating spontaneously combustible materials, water-reactive materials, pyrophoric solids, self-reactive wastes, oxidizers, organic peroxides, and corrosive and infectious wastes.

343. For further guidance on specially engineered landfills, see Basel Convention Technical guidelines on the environmentally sound disposal of hazardous wastes and other wastes in specially engineered landfill (D5) (UNEP, 2022c).

(b) Permanent storage in underground mines and formations

344. Permanent storage in facilities located underground in geohydrologically isolated salt mines and hard rock formations is an option for separating hazardous wastes from the biosphere for geological periods of time. A site-specific security assessment conducted in accordance with pertinent national legislation, such as the provisions contained in 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 Council Directive 1999/31/EC), Annex, appendix A, should be performed for every planned underground storage facility.

345. Wastes should be disposed of in a manner that excludes any undesirable reaction between different wastes or between wastes and storage linings through, among other things, the storage of wastes 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.

346. The following should be considered in the selection of permanent storage for disposal of POP wastes:

- (a) Caverns or tunnels used for storage should be completely separated from active mining areas and areas that may be 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.

4. Other disposal methods when the POP content is low

347. If wastes with a POP content below the low POP content referred to in subsection A of section III above are not disposed of using the methods described above, they should be disposed of in an environmentally sound manner in accordance with pertinent national legislation and international rules, standards and guidelines, including specific technical guidelines developed under the Basel Convention.

348. Depending on, inter alia, the type of waste stream in question, the appropriate disposal method should be chosen to manage the waste in an environmentally sound manner. For example, technical guidelines on the ESM of a number of waste streams have been developed under the Basel Convention and are available from www.basel.int.

349. The application onto land of waste containing or contaminated with POPs, particularly PCDD/PCDFs and dioxin-like PCBs, at concentrations below the low POP content should be carefully assessed and limited or prohibited as appropriate taking into account the precautionary approach. This is needed to avoid unacceptable risks to human health and the environment especially due to the introduction of these substances in the food chain. Limit values contained in the national legislation of Parties regarding different applications of different wastes onto land are reflected in detail in Annex II of this document. This is particularly applicable in the case of disposal operations where sludge, ashes, or other wastes containing or contaminated with POPs may be applied onto land.

350. Examples of pertinent national legislation are given in annex II to the present guidelines.

H. Remediation of contaminated sites

1. Contaminated site identification

351. Poor handling and storage practices in particular may lead to releases of POPs at sites storing these chemicals,⁵⁸ resulting in contamination of the site with high levels of POPs that may pose serious environmental and health concerns. Identification of such sites is the first step in addressing potential concerns.

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

- (a) Identification of suspected sites, such as sites presently or historically involved in:
 - (i) Manufacture of POPs;
 - (ii) Other processes listed in Annex C to the Stockholm Convention leading to the creation of unintentional POPs;
 - (iii) Formulation of pesticides and filling and retrofilling of transformers;
 - (iv) Usage and storage of POPs, such as application of pesticides and placement of transformers and usage of POP-PFASs -containing fire-fighting foams;

⁵⁸ The identification of contaminated sites should also include those where POPs precursors have been used and stored (e.g. the use of sulfluramid as a pesticide which is a PFOS precursor).

- (v) Disposal of POP wastes;
 - (vi) Manufacture of equipment, materials, articles (transformers, capacitors, etc) containing POPs;
 - (vii) Accidents including fires with liquids and other materials containing or polluted with POPs;
 - (viii) Sites for the maintenance of equipment containing 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 to characterize the physical conditions of the suspected site;
 - (d) A detailed testing programme to identify the nature of the site contamination and gather any additional information required.

353. Information on contaminated site identification is widely available. For example, the United Nations Industrial Development Organization (UNIDO) Expert Group on POPs has developed a comprehensive toolkit aimed at assisting developing countries with the identification, classification and prioritization of POP-contaminated sites and with the development of suitable technologies for land remediation, in accordance with best available techniques and best environmental practices (BAT/BEP) (UNIDO, 2010). Other information can be found in the *Reference manual for assessing soil contamination* (FAO, 2000) and the *Guidance document on the management of contaminated sites in Canada* (Canadian Council of Ministers of the Environment, 1997), *Assessment and management of contaminated sites* (Department of Environment Regulation, 2014) and *Brownfields Road Map to Understanding Options for Site Investigation and Cleanup. Sixth Edition* (US EPA, 2017). FAO has published a *Rapid Environmental Assessment (REA) investigator handbook* for assessment of locations thought to be contaminated with pesticides (Ericson et al., 2020).

2. Environmentally sound remediation

354. 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 soil quality criteria depending on the use of the site: industrial (least stringent criteria), commercial, residential or 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 Guidelines⁵⁹ and the Austrian Standard ÖNORM S 2088-2 and in European Commission (2007).

355. Information on methods currently used for the remediation of sites contaminated with POPs, including guidance on site assessment, remediation programs and risk assessment, is available from a variety of sources, including:

- (a) Canada:
Guidance Document on the Management of Contaminated Sites in Canada (Canadian Council of Ministers of the Environment, 1997);

Canadian Federal Contaminated Sites Action Plan (Government of Canada, 2019)
<https://www.canada.ca/en/environment-climate-change/services/federal-contaminated-sites/action-plan.html> ;
- (b) Europe:
Environment Agency Austria portal for international projects on soil contamination
<http://www.umweltbundesamt.at/en/umweltschutz/altlasten/projekte1/international1/> ;

EUGRIS - Portal for soil and water management in Europe
<http://www.eugris.info> ;

NICOLE – Network for Industrially Contaminated Land in Europe
<http://www.nicole.org> ;

⁵⁹ https://www.ccme.ca/en/resources/canadian_environmental_quality_guidelines/, and annex II (examples of pertinent national legislation).

- Joint Research Centre European Soil Data Centre (ESDAC)
<https://esdac.jrc.ec.europa.eu/themes/soil-contamination> ;
- European Environment Agency (EEA): Progress in management of contaminated sites
<https://www.eea.europa.eu/data-and-maps/indicators/progress-in-management-of-contaminated-sites-3/assessment>;
- (c) United Nations Food and Agriculture Organization (FAO):
 Training manual on inventory taking of obsolete pesticides (FAO, 2001)
www.fao.org/agriculture/crops/obsolete-pesticides/resources0/en/ ;
- (d) United States Federal Remediation Technology Roundtable:
 Remediation Technologies Screening Matrix and Reference Guide.
 (US Federal Remediation Technology Roundtable, 2002)
www.frtr.gov/matrix/top_page.html ;
- (e) United States Environmental Protection Agency (US EPA):
 Superfund program
<http://www.epa.gov/superfund/> ;
- Superfund Risk Assessment
http://www.epa.gov/oswer/riskassessment/risk_superfund.htm ;
- Superfund Cleanup Process
<https://www.epa.gov/superfund/superfund-cleanup-process> ;
- Superfund training and learning center
<https://www.epa.gov/superfund/superfund-training-and-learning-center> ;
- Cleaning up Superfund sites
<https://www.epa.gov/superfund/cleaning-superfund-sites> ;
- EPA Contaminated site clean-up information
<https://clu-in.org/> ;
- (f) United States Army Corps of Engineers
 Safety and Health Aspects of HTRW Remediation Technologies (United States Army Corps of Engineers, 2003)
http://140.194.76.129/publications/eng-manuals/EM_1110-1-4007_sec/EM_1110-1-4007.pdf ;
- (g) NATO Committee on the Challenges of Modern Society:
 NATO/CCMS Pilot Study: Evaluation of Demonstrated and Emerging Technologies for the Treatment of Contaminated Land and Groundwater (Vijgen, 2002)
<https://www.clu-in.org/download/partner/2001annualreport.pdf>

I. Health and safety

356. 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 contaminants so that the possibility of exposure is minimized;
- (c) Protect workers by ensuring that they use personal protective equipment.

357. Some countries have issued guidance on taking into account health and safety issues specifically in waste management processes of waste electrical and electronic equipment containing POPs (New Zealand Ministry of the Environment, 2020; HSE UK, 2020). Information on health and safety is also available from ILO (ILO, 1993 and 2004), WHO (WHO, 1995 and 1999), IPCS INCHEM (various dates) the United Kingdom Health and Safety Executive (see *Protection of workers and the general public during the development of contaminated land, Guidance Note HS (G) 66-H HMSO*) and in the Guidance Manual for Hazardous Waste Site Activities (NIOSH, 1985). Examples of practical implementation can be found in UNEP (2001).

358. Health and safety plans should be in place at all facilities that handle POP wastes to ensure the protection of every person in and around such facilities. The health and safety plan for each specific facility should be developed by a trained health and safety professional with experience in managing health risks associated with the specific POPs at the facility.

359. 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 risk to which they are exposed.

360. Different POP waste streams can present significantly different risks depending upon toxicity and exposure. Levels of risk should be established and each situation should be evaluated by health and safety professionals. Two types of situations are discussed below: higher-risk and lower-risk situations.

1. Higher-risk situations

361. Higher-risk situations occur where high concentrations of POPs or high volumes of POP wastes are found and a high potential for exposure of workers or the general population exists. In such situations, 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.

362. Specific technical guidelines on POP wastes will identify higher-risk situations relevant to the specific POPs that they cover.

363. 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, scientific literature and government authorities. Higher-risk situations may occur:

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

364. 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 a statement confirming that they have read it 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) Collective protective measures such as active wet control system (e.g., to prevent contaminated dust from becoming airborne) and passive covering systems (e.g., sealed impermeable high-density polyethylene (HDPE) sheets to reduce dust and vapour diffusion), may be advisable;
- (i) When appropriate, workers entering the site should wear appropriate respiratory protection, and impermeable fabrics should cover their entire bodies (i.e., coveralls with hoods, face shields, gloves and boot covers, or full body suits);
- (j) Spill clean-up kits and personal decontamination materials should be present in all areas containing POPs;
- (k) Workers who are or are expected to be routinely entering sites or working with POPs should undergo medical monitoring, including a baseline medical examination;
- (l) When POPs are to be handled in an open system or when 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;

(m) 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

365. As with high volume or high concentration, there is no international quantitative definition of low volume or low concentration. The terms should thus be defined by comparing contaminant levels with government guidelines or by conducting site-specific risk assessments. Lower-risk situations may occur:

- (a) At sites that contain materials contaminated with POPs in small quantities or at low concentrations;
- (b) In controlled storage rooms that contain small quantities of POPs; and
- (c) At sites contaminated with low concentrations of POPs or where the contamination cannot come directly into contact with people;
- (d) In cases where the POP concentration is low and the POP is inside a polymer.

366. Despite the low level of risk that the situations described above present, 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 response⁶⁰

367. Emergency response plans should be in place for all POPs in production, use, storage and transport or at disposal sites, in line with the exposure and risk profiles of each specific POP. While 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 accidents;
- (b) Identifying relevant local and national legislation governing emergency response plans;
- (c) Planning for anticipated emergency situations and possible responses to them;
- (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 departments, the police and other government emergency response agencies of the location of POPs and their 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) Regularly testing emergency response equipment and reviewing emergency response plans.

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

⁶⁰ 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), or by national, regional or local governments or agencies (such as civil defence and emergency coordination agencies and fire departments). See e.g. Emergency Response Guidebook (2020).

K. Public participation

369. Public participation is a core principle of the 1999 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, the planning of programmes, the development of legislation, the review of documents and data, and decision-making on local issues related to POPs. Paragraphs 6 (g) and (h) of the Basel Declaration reflect an agreement to enhance and strengthen efforts and cooperation to achieve environmentally sound management with regard to the enhancement of information exchange, education and awareness-raising in all sectors of society; and cooperation and partnership at all levels between countries, public authorities, international organizations, industry, non-governmental organizations and academic institutions.

370. The Stockholm Convention, in 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 by providing opportunities for public input at the national level regarding the implementation of the Convention.

371. Articles 6, 7, 8, and 9 of the UNECE 1998 Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention) require the Parties to conduct 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.

372. The participation of the public in the adoption of standards and regulations on 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 should be 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 an interest in POPs;
- (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.

373. 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.

374. An example of public consultation regarding the development of POPs management plans can be found in the Australia Department of the Environment and Heritage (2000) document titled "A case study of problem solving through effective community consultation."

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Annex I to the technical guidelines

International instruments

In addition to the Stockholm and Basel conventions, there are other international instruments or systems that contain provisions pertaining to POPs or POP wastes, including:¹

- (a) 1998 Protocol on Persistent Organic Pollutants to the UNECE 1979 Convention on Long-range Transboundary Air Pollution;
- (b) 2003 Protocol on Pollutant Release and Transfer Registers to the UNECE 1998 Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention);
- (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) 1995 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 (Waigani Convention);
- (e) OECD Decision on the Control of Transboundary Movements of Wastes Destined for Recovery Operations, OECD/LEGAL/0266;
- (f) Rotterdam Convention on Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (1998);
- (g) Globally Harmonized System of Classification and Labelling of Chemicals (GHS).

¹ The reference is made to the most recent version of the instruments, taking into account the possible amendments.

Annex II to the technical guidelines

Examples of pertinent national legislation

Examples of national legislation containing provisions related to the management of POP wastes are outlined below.

Country	Legislation	Brief description
Argentina	Law 25.670/2002 and Decree 853/2007 on PCBs	<ul style="list-style-type: none"> Environmental protection for the management of PCB prohibiting the production, importation and use as well as establishing a procedure to remove functioning equipment containing it due to 2010
Argentina	Law 24.051/1992 and Decree 831/1993 on management of hazardous wastes	<ul style="list-style-type: none"> Reaches all POP wastes that are classified as hazardous waste; includes a destruction efficiency parameter for components in waste incineration
Argentina	Resolution 511/2011 from National Health Service and Food Quality (Servicio Nacional de Sanidad y Calidad Agroalimentaria-SENASA).	<ul style="list-style-type: none"> Prohibits the import of the active ingredient endosulfan and its formulated products and forbids the development, formulation, marketing and use of products containing the active ingredient endosulfan
Austria	Soil Protection Acts	<ul style="list-style-type: none"> Contains stringent limit values for 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 of 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 waste 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 establishments responsible for receiving pesticides packaging.
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 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	PCB Regulations	<ul style="list-style-type: none"> Restrict the manufacture, import, export and sale of PCBs and equipment containing PCBs, and prohibit PCB releases to the environment. The regulations have deadlines ending the use of PCBs and PCB equipment that have concentrations at or above 50 mg/kg along with maximum storage and destruction timelines.
Canada	Prohibition of Certain Toxic Substances Regulations	<ul style="list-style-type: none"> Prohibit the manufacture, use, sale, offer for sale or import of several POPs, as well as products containing these substances.
China	The Action Plan for the Control of New Pollutants http://www.gov.cn/zhengce/content/2022-05/24/content_5692059.htm	<ul style="list-style-type: none"> Request to strengthen the collection, utilization and disposal of waste containing specific new pollutants. 19 POPs were included in the List of New Pollutants for Priority Control (2023 Version).

Country	Legislation	Brief description
		<p>http://www.gov.cn/zhengce/2022-12/30/content_5734728.htm</p> <ul style="list-style-type: none"> For the new pollutants, which has been prohibited, the owner has declared to be abandoned, or collected or received by the relevant departments according to law and in need of destruction, and which are deemed as hazardous waste according to National Catalogue of Hazardous Wastes or the identification standards for hazardous waste, shall be subject to environmental management as hazardous waste.
China	<p>National Catalogue of Hazardous Wastes (2021 Edition) https://www.mee.gov.cn/gzk/gz/202112/t20211213_963867.shtml</p>	<ul style="list-style-type: none"> The list includes, e.g.: Wood preservative waste (HW05): The use of pentachlorophenol in the treatment of waste water sludge from the wood preservative process and waste wood scraps from the wood preservative process contaminated with the preservative (201-001-05). PCBs/PBBs wastes (HW10). Other waste (HW49): Controlled chemical substances under the Stockholm Convention that are banned for use; POPs that has been declared abandoned by the owner, and that has been legally collected or received by the relevant authority and is subject to destruction (900-053-49).
China	<p>Identification standards for hazardous wastes- Identification for toxic substance content (GB 5085.6- 2007) https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/gthw/wxfwjbbfbz/200705/t20070522_103961.shtml</p>	<ul style="list-style-type: none"> Threshold value for each individual chemical of the “dirty dozen (except PCDD/PCDFs)” is 50 mg/kg, respectively. Threshold value for PCDDs and PCDFs is 15 □g TEQ/kg. Chlordecone, lindane, endosulfan, HCBd are in the Annex B (Toxic substance list) of the standard. Threshold value for the total concentration of the substances in Annex B is 3%.
China	<p>Identification standards for hazardous wastes- Identification for extraction toxicity (GB 5085.3-2007) https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/gthw/wxfwjbbfbz/200705/t20070522_103957.htm</p>	<ul style="list-style-type: none"> Threshold values for DDT, HCH, Chlordane, HCB, Toxaphene, Mirex. Pentachlorophenol and its sodium salt, PCB are 0.1, 0.5, 2, 5, 3, 0.05, 50, 0.002 mg/L, respectively.
China	<p>Technical specifications for centralized incineration disposal engineering (HJ 2037)</p>	<ul style="list-style-type: none"> Procedures for incineration of materials containing PCBs
China	<p>Technical specification for co-processing of solid wastes in cement kilns (GB 30760)</p>	<ul style="list-style-type: none"> Procedures for co-processing of POP wastes in cement kilns Limitation for dioxin in cement produced by the co-processing of solid waste
China	<p>Guidelines for the pollution control of dioxins</p>	<ul style="list-style-type: none"> Pollution control of dioxins on 4 key-industries
China	<p>Standards for pollution control on:</p> <ul style="list-style-type: none"> municipal solid wastes incineration (GB 18485) hazardous wastes incineration (GB 18484) co-processing of solid wastes in cement kilns (GB 30485) the steel smelt industry (GB 28664) sintering and pelletizing of iron and the steel industry (GB 28662) 	<ul style="list-style-type: none"> Sets limits for air or water emissions of PCDDs, PCDFs and some other POPs

Country	Legislation	Brief description
	<ul style="list-style-type: none"> • wastes containing polychlorinated biphenyls(GB13015-91) • secondary copper, aluminum, lead and zinc industries(GB 31574-2015) • petrochemical industry(GB 31571-2015) • crematory(GB 13801-2015) • pulp and paper(GB3544-2008) medical waste treatment and disposal(GB 39707-2020)	
Czech Republic	Ministry of Environment Decree on specification of the management of certain waste categories No. 273/2021 Col.	<ul style="list-style-type: none"> • Limit value of 10 ng TEQ/kg is set for the use of waste incineration ash as material for the engineering network constructions. • Limit values for seven indicator PCB congeners in wastes used as material for the engineering network constructions is 0.2 mg/kg dry matter, and for sensitive uses up to 1 m depth and in drinking water protection zones it is 0.05 mg/kg dry matter.
Denmark	Statutory order on residual products, soil and sorted construction and demolition waste	<ul style="list-style-type: none"> • Regulates utilization of construction and demolition waste containing PCB.
Denmark	Statutory order on PCB, PCT and substitutes for these chemical compounds	<ul style="list-style-type: none"> • Regulates sale, import, use, storage and labeling of PCB, PCT and substitutes for these.
Denmark	Statutory order on certain persistent organic pollutants (POP).	<ul style="list-style-type: none"> • Regulates sale, import and use of aldrin, chlordane, dieldrin, DDT, endrin, heptachlor, hexachlorbenzene, mirex and toxaphene.
European Union	Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants Consolidated text (October 2022): http://data.europa.eu/eli/reg/2019/1021/2021-03-15 Regulation (EU) 2022/2400 of the European Parliament and of the Council of 23 November 2022 amending Annexes IV and V to Regulation (EU) 2019/1021 on persistent organic pollutants http://data.europa.eu/eli/reg/2022/2400/oj Corrigendum to Regulation (EU) 2022/2400 of the European Parliament and of the Council of 23 November 2022 amending Annexes IV and V to Regulation (EU) 2019/1021 on persistent organic pollutants. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2022:328:FULL#L_2022328EN.01016901.doc	<ul style="list-style-type: none"> • Article 7 and Annexes IV and V contain provisions regarding the management of wastes containing, consisting of or contaminated with POPs. Annex IV to the regulation contains the low POP content limits applied in the EU. Annex V contains maximum concentration limits of POPs listed in Annex IV, beyond which derogations provided for certain waste streams, under EU law, do not apply. The latter are linked to other disposal methods when destruction or irreversible transformation is not the environmentally preferable option.
European Union	Council Directive 96/59/EC of 16 September 1996 on the disposal of polychlorinated biphenyls and polychlorinated terphenyls (PCB/PCT) Consolidated text: http://data.europa.eu/eli/dir/1996/59/2009-08-07	<ul style="list-style-type: none"> • Contains rules regarding the disposal of PCBs and PCTs, <i>inter alia</i> on the decontamination and/or disposal of equipment and the PCBs therein.
European Union	Directive 2010/75/EU on industrial emissions (Industrial Emissions Directive, IED) Consolidated text: http://data.europa.eu/eli/dir/2010/75/2011-01-06	<ul style="list-style-type: none"> • Annex VI, part 5, contains emission limit values for discharges of PCDD- and PCDF-contaminated wastewater from the cleaning of waste gases. • Annex VI, part 3, contains air emission values for PCDDs and PCDFs.

Country	Legislation	Brief description
European Union	Commission Implementing Decision (EU) 2019/2010 establishing the best available techniques (BAT) conclusions for waste incineration, under the IED (European Commission, 2019b) http://data.europa.eu/eli/dec_impl/2019/2010/oj	<ul style="list-style-type: none"> BAT 30 and table 7 therein with revised emissions levels associated with the BAT for dioxins (PCDDs) and furans (PCDFs) and dioxin-like PCBs.
European Union	Commission Implementing Decision (EU) 2013/163 establishing the best available techniques (BAT) conclusions for the production of cement, lime and magnesium oxide, under the IED (European Commission, 2013b) http://data.europa.eu/eli/dec_impl/2013/163/oj	<ul style="list-style-type: none"> BAT 27 and BAT 52 therein with emissions levels associated with the BAT for PCDD/PCDF from the flue-gases of the kiln firing processes for cement and lime industries.
European Union	Commission Implementing Decision (EU) 2012/135 establishing the best available techniques (BAT) conclusions for iron and steel production, under the IED (European Commission, 2012) http://data.europa.eu/eli/dec_impl/2012/135/oj	<ul style="list-style-type: none"> BAT 25 and BAT 89 therein with emissions levels associated with the BAT for PCDD/PCDF.
European Union	Commission Implementing Decision (EU) 2016/1032 establishing the best available techniques (BAT) conclusions for the non-ferrous metals industries, under the IED (European Commission, 2016) http://data.europa.eu/eli/dec_impl/2016/1032/oj	<ul style="list-style-type: none"> BAT 48, 83, 99, 123, 146 and 159 therein with emissions level associated for PCDD/PCDF
European Union	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 http://data.europa.eu/eli/dec/2003/33(1)/oj	<ul style="list-style-type: none"> Paragraph 2.1.2.2 of the annex contains a PCB limit value of 1 mg/kg for landfilling of inert waste.
European Union	Regulation (EU) 2019/1009 of the European Parliament and of the Council laying down rules on the making available on the market of EU fertilising products. Consolidated text: http://data.europa.eu/eli/reg/2019/1009/2022-07-16	<ul style="list-style-type: none"> Contains a limit value for PCDDs and PCDFs. Annex II. CMC 13: Thermal oxidation materials or derivatives. 20 ng/kg WHO TEQ of PCDD/PCDF /kg dry matter.
Finland	331/2013 Government Decree on Landfills https://www.finlex.fi/en/laki/kaannokset/2013/en20130331_20160960.pdf	<ul style="list-style-type: none"> Sets PCB limit value 1 mg/kg (dm) for waste accepted in landfills for inert waste
Finland	151/2013 Government Decree on Waste Incineration https://www.finlex.fi/en/laki/kaannokset/2013/en20130151_20151303.pdf	<ul style="list-style-type: none"> Sets limit values for waste incineration and co-incineration facilities for <ul style="list-style-type: none"> -air emissions of dioxins and furans 0.1 ng/m³ (n) - waste water emissions of dioxins and furans from exhaust gas cleaning 0.3 ng/m³ (n)
Finland	843/2017 Government Decree on use of certain wastes in soil construction https://www.finlex.fi/fi/laki/alkup/2017/20170843 (in Finnish)	<ul style="list-style-type: none"> Sets PCB limit value 1 mg/kg (dm) for certain waste materials used in soil construction
Finland	466/2022 Government Decree on End-of-Waste Assessment Criteria for Crushed Concrete https://www.finlex.fi/fi/laki/alkup/2022/20220466 (in Finnish)	<ul style="list-style-type: none"> Sets PCB limit value 1 mg/kg (dm) for crushed concrete
France	French Republic, 2011. Arrêté du 18 novembre 2011 relatif au recyclage en technique routière des mâchefers d'incinération de déchets non dangereux, France	<ul style="list-style-type: none"> Limit value for reuse of waste incineration ash for road constructions for PCDD/Fs is set at level 10 ng TEQ/kg dry matter, and for the sum of seven indicator PCB congeners at level of 1 mg/kg dry matter

Country	Legislation	Brief description
Germany	<p>Federal Soil Protection and Contaminated Sites Ordinance Available at http://www.gesetze-im-internet.de/bbodschv/BBodSchV.pdf (in German)</p> <p>[please note: as of 1.8.2023, a revised Federal Soil Protection and Contaminated Sites Ordinance (Article 2 of the Ordinance introducing a Substitute Building Materials Ordinance and amending the Federal Soil Protection and Contaminated Sites Ordinance and the Landfill Ordinance and the Commercial Waste Ordinance) will apply, available at Federal Law Gazette http://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBI&jumpTo=bgbl121s2598.pdf (in German)]</p>	<ul style="list-style-type: none"> • Contains action, test and precautionary values for the evaluation and remediation of sites contaminated with aldrin, DDT, HCB, HCH, PCBs, PCP, PCDDs and PCDFs. • Contains preventive, assessment, warning, intervention criteria for PCBs, HCB, PCP, PFOA, PFHxS, PFOS and other PFAS, PCDD, PCDF and dl-PCB. • Contains test values for HCB, HCH (HCH mixture or beta-HCH), PCP, PCBs, PCDD and PCDF.
Germany	<p>Ordinance on Landfills and Long-Term Storage Facilities Available at http://www.gesetze-im-internet.de/depv_2009/DepV.pdf (in German)</p>	<ul style="list-style-type: none"> • Contains a limit for PCBs in soils used as recultivation layers of landfills. • Prohibits the landfilling of POP-containing waste above the low POP content in Annex IV of Regulation (EU) 2019/1021 in above-ground landfills. • Prohibits the landfilling of waste that could harm public welfare due to its content of long-lived or bio-accumulable toxic substances.
Germany	<p>Ordinance on Underground Waste Stowage Available at http://www.gesetze-im-internet.de/versatzv/VersatzV.pdf (in German)</p>	<ul style="list-style-type: none"> • Contains limits for the use of waste contaminated with PCBs (1 mg/kg in solid material; 0.05 µg/l in eluates) as stowage material.
Germany	<p>Fertilizer Ordinance Available at http://www.gesetze-im-internet.de/d_mv_2012/D%C3%BCMV.pdf (in German)</p>	<ul style="list-style-type: none"> • Contains limits for the sum of PFOS and PFOA (0,1 mg/kg), the sum of, PCDDs, PCDFs and dl-PCB (in the range of 5 - 30 ng TEQ/kg, depending on the application on agricultural land or grassland for forage production) in fertilizers
Germany	<p>PCB/PCT Waste Ordinance Available at http://www.gesetze-im-internet.de/pcbabbfallv/PCBAbfallV.pdf (in German)</p>	<ul style="list-style-type: none"> • Contains requirements regarding the decontamination of equipment and the disposal of PCBs therein. • Contains requirements regarding the selective demolition for removing of PCBs from mineral construction and demolition waste and their disposal.
Germany	<p>POP Waste Monitoring Ordinance Available at https://www.gesetze-im-internet.de/pop-abfall-_berwv/POP-Abfall-%C3%9CberwV.pdf (in German)</p>	<ul style="list-style-type: none"> • Contains rules regarding the separate collection of POP-containing waste exceeding the low POP content in Annex IV of Regulation (EU) 2019/1021, ban of mixing non-hazardous waste containing POPs and monitoring of non-hazardous waste containing POPs. • Contains provisions on the record-keeping and registration obligations for non-hazardous waste containing POPs exceeding the low POP content in Annex IV of Regulation (EU) 2019/1021.
Germany	<p>Sewage Sludge Ordinance Available at http://www.gesetze-im-internet.de/abfkl_rv_2017/AbfklI%C3%A4rV.pdf (in German)</p>	<ul style="list-style-type: none"> • Contains limits for the usage of sewage sludge contaminated with PCBs (0.1 mg/kg), the sum of PCDDs, PCDFs and dl-PCBs (30 ng TEQ/kg) as fertilizer.
Germany	<p>Substitute Building Materials Ordinance (please note: the Substitute Building Materials Ordinance (Article 1 of the Ordinance introducing a Substitute Building Materials Ordinance, and amending the Federal Soil Protection and Contaminated Sites Ordinance and the Landfill Ordinance and the Commercial Waste Ordinance)</p>	<ul style="list-style-type: none"> • Contains limits of PCBs (in the ranges of 0.05 – 0.5 µg/kg in solid material and 0.01 – 0.04 µg/l in eluate) and HCB (in the range of 0.02 – 0.04 µg/l) depending on the material class of excavated soil and dredging spoil or mixed construction and demolition waste for manufacturing of mineral-based substitute

Country	Legislation	Brief description
	will apply as of 1.8.2023, available at Federal Law Gazette http://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl121s2598.pdf (in German))	building material and their installing in technical structures.
Germany	Waste Wood Ordinance Available at http://www.gesetze-im-internet.de/altholzV/AltholzV.pdf (in German)	<ul style="list-style-type: none"> Contains limits for recycling of waste wood contaminated with PCBs (5 mg/kg) and PCP (3 mg/kg).
Germany	Waste Oil Ordinance Available at https://www.gesetze-im-internet.de/alt_lv/Alt%C3%B6lV.pdf (in German)	<ul style="list-style-type: none"> Contains limits for recycling of PCB-contaminated oils (20 mg/kg).
Ghana	Hazardous and Electronic Waste Control and Management-Act, 2016, Act 917	<ul style="list-style-type: none"> Contains elements related to the implementation of the Basel, Rotterdam and Stockholm Conventions, especially on all waste which include POP wastes.
Italy	Part of the Environmental Frame Law concerning waste and soil remediation (Part IV of Legislative Decree No. 152 of 3 April 2006)	<ul style="list-style-type: none"> Contains limits for the regeneration and the co-incineration of PCB/PCT contaminated oils Contains action levels regarding sites (residential, industrial commercial soil and groundwater) contaminated with aldrin, alfa, beta and gamma HCH, chlordane, dieldrin, endrin, DDT, HCB, PCBs, PCDDs and PCDFs.
Italy	Regulations for waste recovery with exemption from permit requirements (simplified administrative procedures) (Ministerial Decree 5/02/1998)	<ul style="list-style-type: none"> Contains limits for PCBs, PCTs and PCDDs in specific types of waste as conditions for exemption from permit requirements
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 dioxin-like PCBs.
Japan	Law Concerning Special Measures for Promotion of Proper Treatment of PCB Wastes (PCB Special Measures Law)	<ul style="list-style-type: none"> Contains standards for the treatment of plastics and metals contaminated with PCBs.
Japan	Soil Contamination Countermeasures	<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 dioxin-like 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.
Netherlands	Removing PCBs Available at: wetten.nl - Regeling - Regeling verwijdering PCB's - BWBR0009821 (overheid.nl) https://wetten.overheid.nl/jci1.3:c:BWBR0009821&z=2011-03-05&g=2011-03-05	<ul style="list-style-type: none"> Contains limits for the removal of PCB's from equipment (0.5mg/kg).
Netherlands	Soil Quality Regulation (Dutch: <i>Regeling bodemkwaliteit</i>) Annex A, Table 2 Available at: wetten.nl - Regeling - Regeling bodemkwaliteit - BWBR0023085 (overheid.nl) https://wetten.overheid.nl/jci1.3:c:BWBR0023085&z=2022-10-01&g=2022-10-01	<ul style="list-style-type: none"> Maximum allowed concentrations of (a.o.) PCBs in soil, sludge, and construction materials. Sum of 7 PCBs (28, 52, 101, 118, 138, 153 and 180): 0.5 mg/kg
Netherlands	Organic halogen compounds in fuels Available at: wetten.nl - Regeling - Besluit organisch-halogeengehalte van brandstoffen - BWBR0004501 (overheid.nl) https://wetten.overheid.nl/jci1.3:c:BWBR0004501&z=2016-05-24&g=2016-05-24	<ul style="list-style-type: none"> Maximum amount of PCB's in fuels of 0.5 mg/kg per congener. Maximum amount of organic halogen compounds of 50mg/kg.

Country	Legislation	Brief description
Netherlands	Determination method for organic halogen compounds in fuels Available at: wetten.nl - Regeling - Regeling bepalingsmethoden organisch-halogeengehalte van brandstoffen - BWBR0004524 (overheid.nl) https://wetten.overheid.nl/jci1.3:c:BWBR0004524&z=2009-12-02&g=2009-12-02	<ul style="list-style-type: none"> • Contains determination methods for PCB's in fuels. • Contains determination methods for organic halogen compounds in fuels.
Netherlands	Handelingskader PFAS. This is not national legislation, but is a national implementation of duty of care obligations following from national soil legislation. Available at: 2021335279-1-geactualiseerde-versie-handelingskader-pfas.pdf (overheid.nl) https://open.overheid.nl/documenten/ronl-96a54784-bc6d-4c1f-b99e-862a347554fd/pdf	<ul style="list-style-type: none"> • Contains limit values for PFOS, PFOA and other PFAS in soils and dredged materials, which regulate the further use of soils and dredged materials contaminated with these substances depending on different use scenarios.
New Zealand	Hazardous Substances and New Organisms Act 1996	<ul style="list-style-type: none"> • Prohibits the import, manufacture, use or storage of POPs (sections 25A – 25D, Schedule 1AA, Schedule 2A).
New Zealand	National Environmental Standards for Air Quality (Resource Management (National Environmental Standards for Air Quality) Regulations 2004)	<ul style="list-style-type: none"> • Contains standards banning activities discharging significant quantities of dioxins and other toxics into the air, and standards for ambient (outdoor) air quality.
Norway	Norwegian Product Regulations, Chapter 2 on Regulated substances, preparations and products.	<ul style="list-style-type: none"> • Contains a ban on the production, use, import and export of PCBs, including PCB-containing capacitors.
Norway	Norwegian Waste Regulations, Chapter 14 on Discarded insulating glass units containing PCBs	<ul style="list-style-type: none"> • Lays down requirements for the producers to collect and handle obsolete windows that contain PCBs.
Norway	Norwegian Pollution Regulations, Chapter 2 on Clean-up of contaminated soil	<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.
Sweden	Regulation (2007:19) on PCB etc Available on: Förordning (2007:19) om PCB m.m. Svensk författningssamling 2007:2007:19 t.o.m. SFS 2020:689 – Riksdagen https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/forordning-200719-om-pcb-mm_sfs-2007-19	<ul style="list-style-type: none"> • Closed applications: Prohibits use of equipment i.e. transformers and capacitors with 2 kVA output effect containing >0.0002 % (2 mg/kg) PCB. • Open applications: Inventory requirements regarding buildings and constructions erected or renovated between the years 1956 -1973. Requirements for buildings and constructions regarding removal of sealants and flooring material containing >0.0500 % (500 mg/kg) PCB. Requirements for buildings and constructions regarding removal of sealants and flooring material containing 0.0050 – 0.0500 % (50-500 mg/kg) PCB.
Switzerland	Soil Burden Ordinance	<ul style="list-style-type: none"> • Contains action levels regarding sites contaminated with PCBs, PCDDs and PCDFs.
United Kingdom	The Persistent Organic Pollutants Regulations 2007 (as amended) Retained Regulation (EU) 2019/1021 of the European Parliament and the Council on persistent organic pollutants (recast), as amended by: <ul style="list-style-type: none"> • The Persistent Organic Pollutants (Amendment) (EU Exit) Regulations 2020 • The Persistent Organic Pollutants (Amendment) (EU Exit) Regulations 2022 The Environmental Protection (Disposal of Polychlorinated Biphenyls and other Dangerous Substances) (England and Wales) Regulations 2000, as amended by:	<ul style="list-style-type: none"> • These Regulations implement the Stockholm Convention.

Country	Legislation	Brief description
	<ul style="list-style-type: none"> • The Environmental Protection (Disposal of Polychlorinated Biphenyls and other Dangerous Substances) (England and Wales) (Amendment) Regulations 2020 	
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.
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.