GUIDANCE ON ESTIMATING BASELINE DIOXIN RELEASES FOR THE UNDP GLOBAL HEALTHCARE WASTE PROJECT

NAME OF THE MODEL FACILITY _____

INTRODUCTION

Reducing or eliminating releases of polychlorinated dibenzo-p-dioxins and dibenzo furans (herein referred to simply as "dioxins") through the application of best environmental practices and best available techniques in the health sector is one of the main objectives of the UNDP GEF project. The Global Environment Facility and the parties to the Stockholm Convention are interested in the quantities and cost-effectiveness of dioxin reduction by the different approaches being demonstrated in this project towards meeting the overall objectives.

This guidance describes various methods for estimating total dioxin releases, present and/or past, prior to the intervention of the UNDP GEF project, thus establishing a baseline for the purpose of calculating cost-effectiveness.

GENERAL APPROACH

The estimation methods in this guidance should be used to estimate dioxin releases specific to a model healthcare facility, a model centralized treatment plant (if applicable), a model immunization program (if applicable), and to compare them with national estimates from the country's dioxin inventory under the Stockholm Convention. This guidance also includes estimation methods for other persistent organic pollutants that may be found in the model facility or plant.

The technical consultant or facility engineer should use different estimation methods for comparison: results of stack testing and residue analysis if available, estimates using emission factors, and data from the national dioxin inventory.

Dioxin releases are estimated in terms of µg I-TEQ per year (micrograms International-Toxic Equivalent per year). As much as possible, I-TEQ should be used. However, some sources may present TEQ data using other toxic equivalent factors, in particular, the WHO-TEQ and Nordic-TEQ. Annex A compares the commonly used toxic equivalent factors. If there is insufficient information to convert to I-TEQ, make a note which TEQ was used in your final report.

The estimation method requires an activity rate, which in the case of incineration is the tonnes of waste incinerated per year.

The basic equation for estimating dioxin releases per year is given by:

(1) **Releases per year** (µg I-TEQ / year) = (**Emission Factor** $_{air}$ + **Emission Factor** $_{residue}$) (µg I-TEQ / tonne of waste processed) x **Activity Rate** (waste processed, tonnes / year)

The main source of dioxins in the health sector is combustion of healthcare waste and combustion-related processes (open burning, different kinds of incineration, gasification, rotary kiln furnaces, plasma pyrolysis, etc.). This guidance assumes open burning, drum "incinerators", single-chamber oven-type brick or metal burners, rotary kiln furnaces, and dual-chamber incinerators are the most common combustion methods used by health facilities in developing countries. [Note: If burning in boilers, high-temperature gasification, plasma, fluidized bed, or other high-temperature systems are used, notify the global project team to obtain a different set of emission factors.]

To use equation (1) above, the most appropriate emission factors[1] are needed. Emission factors for releases to air and residues (fly ash and bottom ash) for 22 of the most common types of healthcare waste incinerators are given in Annex C. Since emission factors are not available for every single type of incinerator, the technical consultant or facility engineer has to make a judgment on which combustion method closely resembles the type of incinerator at the facility. Descriptions of the common types of incinerations are presented in Annex B. In addition to incinerator design, emission factors are also dependent on the type of waste fed, segregation practices, operating conditions, the maintenance conditions of the incinerator and of any air pollution control devices, and other factors that are difficult to account for in a dioxin release estimate. The consultant or facility engineer should keep in mind the major aspects that influence dioxin formation when making a judgment on which emission factors to use.

Aspects of Dioxin Formation to be Considered When Selecting Emission Factors

It is generally accepted that the bulk of dioxins from incineration comes from *de novo* synthesis, that is, the creation of dioxins after the combustion process as the gases cool down to the temperature range favorable to dioxin formation. Dioxins are formed in the presence of chlorine even in small amounts. The positive relationship between dioxin releases and the chlorine content of waste was shown in a series of experiments that found the amount of dioxin formed in incinerator exhaust gases generally correlated with the amount of chlorine in the materials incinerated.[2] For the purpose of this estimation, a polyvinyl chloride (PVC) content in the healthcare waste stream of about 7% is

[1] Although the term "emission" refers specifically to releases to the air, the term "emission factor" could mean releases to air, water or solid residue.
[2] T. Shibamoto, A. Yasuhara *et al*. "Dioxin Formation from Waste Incineration." *Reviews of Environmental Contamination and Toxicology* 190: 1-41 (2007).

assumed when possible[3]. Note that even higher PVC levels may be found in the healthcare waste streams of many countries. It should also be mentioned that many healthcare facilities use sodium hypochlorite (bleach) as a disinfectant and often soak sharps and other waste in hypochlorite solution, thereby further increasing the chlorine content.

Another factor that favors dioxin formation is the presence of metals—such as copper, iron, and zinc—which act as catalysts in the reaction. Hence, it is important to take note whether the inside surfaces of the incinerator and stack (chimney) are made of brick or metal, such as galvanized iron or stainless steel.

Incomplete combustion of the waste leads to particulate matter and other products of incomplete combustion, some of which act as precursors to the formation of dioxins. A combustion chamber or furnace operating at all times above 850ºC is important in reducing dioxin formation. Incinerators operating even at high temperatures produce dioxins during both normal and transient conditions. However, dioxin formation is generally greater during transient conditions, such as start-ups and shutdowns, when the combustion temperature drops below 850ºC. When selecting the emission factors, take note of the temperature of the primary (combustion) chamber or furnace. A combustion chamber that does not have auxiliary burners and temperature controllers cannot maintain the combustion chamber temperatures above 850ºC at all times. Also, take note whether or not the incinerator has an auger or ram feed assembly with good temperature control to maintain the chamber temperature above 850ºC during waste feeding.

To ensure a higher degree of combustion, a secondary chamber is used to heat the gases to even higher temperatures through the use of one or more afterburners. Dioxins can be reduced with a secondary chamber in which the gases from the primary chamber are further heated to 1100ºC for a period of at least 2 seconds (referred to as the residence time or retention time). When selecting the emission factors, take into account whether or not the incinerator has only one chamber or two chambers. In the latter case, consider both the temperature and residence time in the secondary chamber. An afterburner is essential to achieve high temperatures in the secondary chamber. Some manufacturers may not specify the secondary chamber residence time. If the secondary chamber is smaller in size than the primary chamber and does not have internal baffles, it is likely that the residence time is much less than 2 seconds.

Despite high temperatures in the primary and secondary chambers, most dioxins are created after combustion. The temperature range in which dioxins are formed is between about 450ºC and 250ºC. The longer the

[3] U.S. EPA field test data showed that infectious waste contains about 2.8% chlorine ± 1%; see G. England *et al.* (1991 and 1992), cited in W.R. Seeker, Chapter 5, in *Environmental Management in Healthcare Facilities*, K.D. Wagner (editor), Philadelphia: W.B. Saunders Company (1998). Since chlorine is 57% of PVC, and typical flexible PVC plastics used in hospitals have about 30% or more of plasticizers, UV stabilizers, and other additives, then assume that a typical infectious waste bag contains about 7% PVC. Note that others have estimated that PVC plastics comprise 14 to 30% of non-infectious medical waste (D. Hickman *et al.*, "Cadmium and lead in biomedical waste incinerators," presented at the 82nd Annual Meeting of the Air & Waste Management Association, Anaheim, CA, June 1989).

gases remain in this range, the more dioxins are formed. Incinerators with quenching systems (such as direct water injection or lime slurry semi-dry scrubbing) cool the gases quickly and minimize dioxin formation. On the other hand, heat exchangers and heat recovery boilers, while recovering energy for other uses, tend to create more dioxins in the heat exchanger or boiler section. Incinerators with short chimneys and hot exhaust gases may form dioxins in the gas plume after it leaves the chimney. Stack tests conducted on samples of hot exhaust gases above 450ºC would underestimate dioxin releases. When selecting emission factors, the distance traveled by the hot gases and the length of time to cool them should be considered.

Even with high primary and secondary chamber temperatures and long residence times, air pollution control (APC) devices are needed to reduce dioxin releases to air to within international standards (0.1 ng I-TEQ/Nm3). However, while APC devices may reduce dioxin releases to air, they may also increase dioxin releases in fly ash. Indeed, the greatest portion of total dioxin output is found in the incinerator residues, especially fly ash. There are no international standards for dioxins in incinerator residues. However, some countries have established limits for dioxins in incinerator residues and/or total dioxin releases per tonne of waste incinerated. For example, in Japan the guideline for total dioxin output (stack gases and residues) from incinerators is 5 µg/tonne of waste.[4]

Examples of APC devices used for medical waste incinerators are fabric filters or baghouse filters used at temperatures below 260ºC, cyclones used to remove the larger particles (but ineffective for small particles), electrostatic precipitators used at temperatures of around 450ºC (although they may promote dioxin formation if operated at lower temperatures), catalytic oxidation, gas quenching, catalyst-coated fabric filters, and different types of wet and dry scrubbers using mixtures of activated charcoal, lime or limestone solutions. Often a combination of devices is used, such as a dry scrubber with activated carbon injection and a baghouse filter. The use of air pollution control equipment results in different emission factors.

Other factors that can increase dioxin formation are low turbulence and poor gas mixing in the secondary chamber, as well as low oxygen in the secondary chamber. (Note that high air flow rates in the primary chamber can lower primary chamber temperatures and raise particulate matter emissions thereby increasing dioxin releases.) The presence of sulfur in the waste, the frequency of transient conditions (e.g., fluctuations in temperature in the chambers), start-up and shut-down conditions, etc. also influence dioxin releases.

Since significant amounts of dioxin are found in incineration ash, the annual release values relative to the incinerator ash residue must always

[4] Ministry of Health and Welfare, 1997 Guideline for Controlling Polychlorinated Dibenzo-p-dioxins and Dibenzofurans (PCDDs/DFs) of MSW Incinerators in Japan, in Makoto, S., Yoji, S., Yasuhiro, I.,Toru, K., Teruaki, T., Osamu, F. 1998. Reduction of total dioxin emission from MSW incinerators. Organohalogen Cpds. 36: 325-328

be included. Emission factors for incinerator residues (bottom ash and fly ash captured in dust removal systems) are found in Annex C.

ESTIMATING TOTAL DIOXIN RELEASES

1.0 Define the baseline period

Define the baseline period (reference date) during which healthcare waste was burned or incinerated at the model healthcare facility or at a centralized treatment plant. The reference date could be just prior to the introduction of best techniques and practices. Or if little or no healthcare wastes are currently being burned at the model healthcare facility or centralized treatment plant, define a reference date when most or all healthcare waste was burned or incinerated in the past, such as before the PDF-B phase in 2003 or before non-burn technologies were installed.

Reference Date (select one):

- ☐ Now (specify today's date: _____)
- ☐ Period before the PDF-B phase (specify year: _____)
- ☐ Year before non-burn technology was installed (specify year: _____)

2.0 Estimate the total amount of waste burned

Estimate the amount of healthcare waste burned or incinerated in the model healthcare facility or centralized plant today if waste is still burned (i.e., prior to the introduction of best techniques and practices) or in the past (that is, before the PDF-B phase in 2003 or before the use of non-burn technologies). Annex D shows data on waste generation rates in different countries. Use any available past data or extrapolate from data gathered during the baseline assessment. Calculate the amount on an annual basis in metric tonnes per year (1 tonne = 1000 kg or 2205 pounds) and report that value in (a) below.

Table A: Activity rate

Total amount of healthcare waste burned or incinerated during the reference year	=	(a) _____	tonnes per year
Total amount of hazardous chemical waste burned or incinerated separately during the reference year	=	(b) _____	tonnes per year
Total amount of municipal solid waste burned or incinerated separately during the reference year	=	(c) _____	tonnes per year

If hazardous chemical wastes (such as laboratory solvents, expired pharmaceuticals, chemotherapeutic or cytotoxic agents, spent chemical disinfectants, etc.) are/were incinerated *separately* in a hazardous waste incinerator, report that value in (b) above. If municipal solid waste (regular waste, i.e., non-infectious, non-hazardous) from the facility

is/was also incinerated in a *separate* municipal waste incinerator, provide an estimate in (c) above.

Finally, provide a description listing the types of waste burned (e.g., infectious waste, hazardous chemical waste, mixture of infectious and chemical waste, municipal solid waste (or regular waste), all waste, etc.)

_____

_____

3.0 Select the method of combustion used

Review the descriptions of different combustion methods and air pollution control devices in Annex B. Select the combustion method that best matches the one used by the facility or centralized treatment plant. Keep in mind the various factors that influence dioxin formation when making your selection.

4.0 Allocate waste quantities to combustion method(s)

Use the table below to describe the combustion method used and the amount of waste burnt in tonnes per year.

If more than three methods of combustion are used, add more rows to Table B as necessary. List the different methods in the first column and place the corresponding amounts of waste in the second column; the sum of the amounts in the second column should equal the total of the values shown in (a), (b), and (c) in Section 2.0.

Table B: Combustion methods used and corresponding amounts burnt

Combustion method	Amount of waste burnt in tonnes/yr

If a combustion method (above) is not described by any of the methods listed in Annex B, give a detailed description of the method used below and notify the global project team to obtain appropriate emission factors:

_____

_____

_____

As part of the documentation, take digital photos of each combustion method used and attach the photos to this report. If the combustion methods are no longer used, obtain copies of any available old drawings or photos of the incinerators used and attach scanned copies to this report.

5.0 Calculate dioxin releases from combustion sources

I. Dioxin emissions based on incinerator stack test data

Isokinetic stack gas sampling and certified chemical analysis using internationally approved test methods are expensive, require specialized instrumentation, and their accuracy depends, among others, on the representativeness of the waste stream and the incinerator's operating conditions during the test, the training and experience of the personnel conducting the tests, and quality control / quality assurance. If stack tests were conducted on one or more incinerators, report the data in this section. Air emission data are typically given in ng I-TEQ/Nm^3. [5]

For the purpose of this guidance, test results obtained using internationally approved standards for dioxin and furan measurements will be given priority. However, stack sampling, sample collection and recovery, sample extraction and cleanup, and chemical analysis and quantification must fully comply with any one of the following test methods:

- EN 1948, volumes 1-3: Stationary source emissions-determination of the mass concentration of PCDDs/PCDFs. European Standard approved by CEN on January 23, 2006.
- EPA method 23: Determination of Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans from Municipal Waste Combustors. United States Standard.
- VDI 3499, sheets 1-3: A Standard Guideline for the Determination of PCDD/F emissions from stationary sources, Sheet 1-3, 2003. German Standard.
- Environment Canada Method: A Method for the Analysis of Polychlorinated Dibenzo-Para-Dioxins (PCDD), Polychlorinated Dibenzofurans (PCDF) and Polychlorinated Biphenyls (PCB) in Samples from the Incineration of PCB Waste, Report EPS 1/RM/3. Canadian Standard.

Quality control and quality assurance procedures, including the use of method blanks and matrix spikes, recovery of internal standards, quantification of labeled standard substances using isotope dilution techniques, and reporting of limits of quantification and detection limits, must be adhered to. Moreover, the laboratory conducting the tests must be accredited for dioxin testing under an accreditation standard or

[5] For educational purposes, note that the guidelines for best available techniques under the Stockholm Convention limit the levels of dioxins and furans in air emissions to 0.1 ng I-TEQ/Nm^3 at 11% O_2. This is also the emission limit for dioxins and furans in the European Union and in various countries. In Japan, new large incinerators have to meet the same 0.1 ng I-TEQ/Nm^3 limit while small to medium incinerators are allowed between 1 to 5 ng I-TEQ/Nm^3 depending on size. The current limit for new incinerators in the United States is 0.6 to 2.3 ng TEQ/dsm^3 at 7% oxygen depending on size; on December 2008, the US EPA proposed more stringent limits of between 0.008 to 0.014 ng TEQ/dsm^3. The limit for Canada is 0.08 ng I-TEQ/Rm^3 at 11% O_2. To convert between different reference conditions, note that: "N" refers to normal conditions (273ºK, 101.3 kPa, dry, 11% O2); "ds" refers to US standard conditions (293ºK, 101.3 kPa, dry, 7% O2); and "R" refers to Canadian reference conditions (298 ºK, 101.3 kPa, dry, 7% O2).

program—such as European Norm EN 45001, National Environmental Laboratory Accreditation Program (NELAP) in the US, or Specified Measurement Laboratory Accreditation Program (MLAP) in Japan—and certified for dioxin testing by a recognized national body such as the Deutsche Akkreditierungsstelle Chemie (DACH) in Germany, National Institute of Technology and Evaluation in Japan, or the UK Accreditation Service.

A stack sampling time of 8 hours and a burn rate at the rated capacity of the incinerator using representative healthcare waste samples should be used. Emission data are typically presented as ng I-TEQ/Nm^3 but should be converted to an emission factor in µg TEQ/tonne. To convert to µg TEQ/tonne, multiply the ng I-TEQ/Nm^3 by the volume-to-mass ratio [m^3 of gas per kg of waste burnt). If the data are not available from test results, use the ratios given in Table C. Note that ng I-TEQ/kg is equal to µg TEQ/tonne. See Annex E for common units and conversion factors.

Table C: Volume-to-mass ratio if data are not available from the test report

UNEP classification	Description	Volume/Mass ratio*
Class 1	Small, simple, batch type incinerator, uncontrolled, with no secondary combustion chamber, no temperature control, no air pollution control	20
Class 2	Controlled, batch type combustion, with an afterburner, no or minimal air pollution control	15
Class 3	Controlled, batch type combustion, with air pollution control, such as an electrostatic precipitator or baghouse; this includes many centralized plants	15
Class 4	High technology, continuous, controlled combustion, sophisticated air pollution control, waste is fed into furnace above 900C	10

* in m^3/kg of waste burnt

Input your data in Table D below.

Table D: Dioxin estimates based on stack test data (if available)

Name of incinerator: _____						
Amount of waste burnt (tonnes/yr) _____	x	Dioxin/Furan concentration in air (ng I-TEQ/Nm^3) _____	x	Volume/Mass ratio* _____	=	Dioxin emission for air (µg TEQ/year) _____
Amount of waste burnt (tonnes/yr) _____	x	Dioxin/Furan concentration in ash (ng I-TEQ/g) _____	x	Grams of ash per kg of waste** _____	=	Dioxin release for residue (µg TEQ/year) _____

* Use Table C if data from the actual test are not available
** Use 200 g/kg if data from the actual test are not available

If tests of more than one incinerator or combustion method were conducted, add more boxes above as necessary. If dioxin tests were conducted on the residues, the data are usually given in ng I-TEQ/g of

ash. Multiplying the concentration (ng I-TEQ/g) by grams of ash per kg of waste burnt gives the dioxin release in the residue. If actual data on the mass of ash residue per mass of waste burnt were not obtained during testing, assume the residual ash is 20% of the mass of the original waste. If no dioxin measurements were done on the residues, use an appropriate emission factor for residues from Annex C.

NOTE: If tests were not conducted in accordance to international norms and standards and/or if the laboratory was not accredited, perform the calculations and report the results but add a note in the report stating that the tests differed from the norms or standards and/or that the laboratory lacked accreditation.

II. Dioxin releases based on combustion emission factors

For each combustion method listed in Section 4, obtain the corresponding emission factors for both air and residue from Annex C. Note that the first table in Annex C refers to healthcare waste combustion (such as hospital incinerators) and the second table refers to hazardous chemical waste incinerators. Place the appropriate emission factors in the table below and calculate the dioxin releases in air and residue using equation (1) above. Add more boxes under Table E as necessary.

Table E: Dioxin estimates based on emission factors

Combustion method:				
Amount of waste burnt using this combustion method (tonnes/yr)	x	Emission factor for air (µg TEQ/tonne)	=	Dioxin emission for air (µg TEQ/year)
	x	Emission factor for residue (µg TEQ/tonne)	=	Dioxin release for residue (µg TEQ/year)

Combustion method:				
Amount of waste burnt using this combustion method (tonnes/yr)	x	Emission factor for air (µg TEQ/tonne)	=	Dioxin emission for air (µg TEQ/year)
	x	Emission factor for residue (µg TEQ/tonne)	=	Dioxin release for residue (µg TEQ/year)

III. Comparison of dioxin estimates from the national dioxin inventory

Obtain a copy of the country's national dioxin inventory and attached a copy of the sections of the report dealing with incineration of hospital wastes. Be sure to include the sections that describe how the estimates were obtained. Summarize the results in Table F below. Add more rows if estimates were calculated for multiple years.

Table F. National dioxin estimates from the country's dioxin inventory

Year	Number of hospital incinerators in the country	Total amount of healthcare waste burned (tonnes/yr)	Dioxin emission for air (µg TEQ/year)	Dioxin release for residue (µg TEQ/year)	Total dioxin releases (µg TEQ/year)

6.0 Estimates of other persistent organic pollutants (POPs) under the Stockholm Convention

Conduct a thorough search of the facility for any of the chemicals listed in Annex F. Take digital photographs of any of these chemicals if they are found and attach the photographs to this report. In Table G, provide the information requested. For each POP chemical, describe the container used and the storage location. If possible, weigh the container and estimate the quantity (in liters) of chemical inside. Take note of any identifying labels and markings. Add more columns to Table G if needed.

Table G. Inventory of other persistent organic pollutants (POPs) in the facility

Common name of chemical	(1)	(2)
Name in the container label		
Identifying mark or serial number		
Physical state (i.e., solid, liquid, sludge, or gas)		
Weight of container (in kilograms)		
Estimated volume of chemical (in liters)		
Estimated concentration of chemical if known (include units)		
If still used, estimated amount (in kg or liters) consumed per year		
Description of use in the facility		
Description of condition of the container		
Description of the storage location		
Other comments		

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ANNEX A

Comparison of Toxic Equivalent Factors for Commonly Used TEQs

Congener	I-TEQ	WHO-TEQ	Nordic-TEQ
DIOXINS			
2,3,7,8 TCDD	1	1	1
1,2,3,7,8 PeCDD	.5	1	.5
1,2,3,4,7,8 HxCDD	.1	.1	.1
1,2,3,7,8,9 HxCDD	.1	.1	.1
1,2,3,6,7,8 HxCDD	.1	.1	.1
1,2,3,4,6,7,8 HpCDD	.01	.01	.01
OCDD	.001	.0001	.001
FURANS			
2,3,7,8 TCDF	.1	.1	.1
2,3,4,7,8 PeCDF	.05	.05	.01
1,2,3,7,8 PeCDF	.5	.5	.5
1,2,3,4,7,8 HxCDF	.1	.1	.1
1,2,3,7,8,9 HxCDF	.1	.1	.1
1,2,3,6,7,8 HxCDF	.1	.1	.1
2,3,4,6,7,8 HxCDF	.1	.1	.1
1,2,3,4,6,7,8 HpCDF	.01	.01	.01
1,2,3,4,7,8,9 HpCDF	.01	.01	.01
OCDF	.001	.0001	.001

ANNEX B

Description of Some Combustion Methods

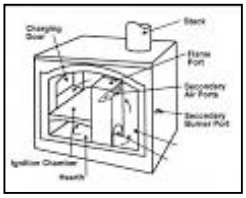
1. Open burning (open fire burning) is simply piling up the healthcare waste into a mound or in a shallow hole, often pouring kerosene or other flammable material, and burning the waste pile on the ground. In addition to dioxins, open burning emits other pollutants and poses a danger of spreading fire. Moreover, open burning does not fully disinfect the waste, does not remove the physical hazard associated with sharps, and exposes waste pickers and waste recyclers to dangerous pathogens. *(Examples: open burning on hospital grounds, open burning in dumpsites, open burning in landfill trenches, open burning in pits)*

2. A single-chamber, oven-type brick incinerator is a small burner made of bricks or concrete and is commonly used in developing countries. It is operated in a batch mode. It has a door at the top or side leading to a chamber where the healthcare waste is burned. It may or may nor have a metal grill and a bottom compartment to collect the ash. A brick incinerator often has holes on the sides to allow air in and a brick or metal chimney at the top to direct the smoke upwards. It has no temperature controls and no pollution controls. *(Examples: Bailleul incinerator, traditional locally-made brick incinerators)*

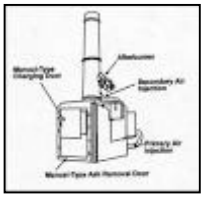
3. A small dual-chamber brick incinerator with no air pollution control is generally made of fire bricks cured with refractory mortar and positioned with a metal frame. These designs are also commonly used in developing countries. Temperatures in the primary combustion chamber with supplementary fuel can reach about 800ºC but temperatures in the small secondary chamber are generally at about 600ºC. The combustion chamber may have a steel grate leading to a small bottom ash compartment. The secondary chamber does not have an afterburner and has a very short residence time (usually < 0.2 seconds). The incinerator has a metal chimney of about 4 meters in length. Wood, kerosene or diesel may be added as supplementary fuel to the primary chamber. It has no temperature and pollution controls. These incinerators are sometimes used to burn only safety boxes containing sharps. *(Examples: De Montfort models Mark I to Mark 8a and Mark 9)*

4. A small single-chamber metal incinerator has a single burning chamber made of steel usually with a short metal chimney. The opening is generally on the side. The outside surface of the incinerator may be covered with insulating bricks but the interior areas where combustion takes place and where the exhaust gases pass are made of metal. It has no pollution control and no temperature controls. *(Example: SICIM Pioneer AC/01 incinerator)*

5. A steel drum or metal barrel "incinerator" typically uses a 210-liter or 55-gallon metal drum or a small galvanized barrel, often with a screen at the bottom to separate the ash, and a screen at the top to prevent some of the ash from blowing out. It may or may not be fitted with a small metal pipe to act as a chimney. It has no temperature control and no pollution controls. *(Example: Dunsmore drum incinerator)*

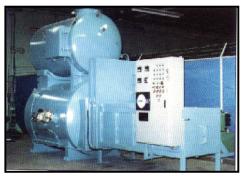


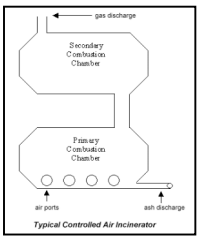
6. A multi-chamber excess air incinerator has two or more combustion chambers and may be of the retort type as shown in the drawing. The first chamber generally burns the waste at around 760ºC. A burner in the second chamber burns the flue gas. These incinerators typically use more than double the amount of air in the primary chamber than that needed for complete combustion. *(Example: Plibrico excess air batch unit)*



7. A dual-chamber controlled-air incinerator with a small secondary chamber, an afterburner and no air pollution control is also used in low to medium income countries. A controlled-air incinerator is sometimes called a starved-air incinerator, pyrolytic incinerator, or modular incinerator. They have an internal refractory lining in the primary combustion chamber and have a small secondary chamber on top of or beside the primary chamber. Because they have auxiliary burners burning diesel, gas or other fuel in the primary chamber, they can reach combustion temperatures of 750ºC and higher. They have an afterburner in the secondary chamber capable of reaching 900 to 1000ºC with a short residence time of about 1 second. Temperatures are maintained by a simple controller. The primary chamber has a steel grate through which ashes fall into a bottom ash compartment accessible through an ash removal door. These incinerators have metal chimneys that are about 10 meters high. Except for the afterburner, there are no pollution controls. *(Example: Vamed Hoval models CV1 and CV2 incinerator)*

8. A tubular incinerator is a single-chamber incinerator (internal diameter less than 0.6 meters, height no more than 2 meters) with a bell-shaped system connecting the tubular chamber to the stack. The bell-shaped system allows air dilution of the exhaust gas. They are controlled by two burners and have no air pollution control. Hospital waste is loaded manually and the incinerator operates in the batch mode.





9. A dual-chamber controlled-air incinerator with a large secondary chamber, an afterburner, and some air pollution control may be found in large hospitals and in centralized treatment facilities. As noted above, a controlled-air incinerator is sometimes called a starved-air incinerator, pyrolytic incinerator, or modular incinerator. It has an internal refractory lining in the primary combustion chamber and has a large secondary chamber on top of or beside the primary chamber. Because it has auxiliary burners (using diesel, gas, or other fuel) in the primary chamber, it can reach combustion temperatures of about 750ºC to 850ºC. The primary chamber has a steel grate leading to an ash pit or ash sump. The secondary chamber has one or two afterburners capable of reaching 1000ºC with a residence time of between 1 to 2 seconds. The incinerator may have a low-efficiency air pollution control device such as a cyclone separator. These incinerators have chimneys that may be as high as 20 meters.

11 & 15. A rotary kiln incinerator has a cylindrical primary combustion chamber (kiln) which rotates horizontally at about one full rotation per minute. It is often tilted slightly to move the waste away from the charging door such that by the time the waste reaches the opposite end, only ash remains. Depending on the design, the temperatures in the kiln range from 700 to 1000ºC. Burners in the secondary chamber maintain high temperatures.

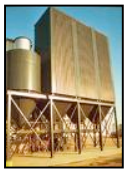
12. A pathological waste incinerator or crematory is generally a refractory-lined incinerator designed to burn human or animal remains, anatomical parts, and/or tissue. They generally have two chambers. Burners in the primary chamber are needed to incinerate body parts. The secondary chamber is often built beneath the primary chamber. Old systems generally do not have good temperature control and no air pollution control.

13 & 17. Air Pollution Control Devices: Many general batch-type incinerators use a baghouse filter to remove particulate matter (dust) as shown in the picture. The baghouse is an assembly of filter bags or fabric filter tubes suspended inside a large enclosure. The exhaust gas has to pass through

these bags to exit the unit. Fly ash and other particles then collect on the filter bags to form a dust cake. Different methods are used to dislodge the dust cake, such as reverse air flow, mechanical shakers, or a pulse jet. Electrostatic precipitators use high-voltage fields to apply electrical charges to the particles, causing the charged particles to move toward an oppositely charged collection surface, where they accumulate.

14. A dual chamber controlled air incinerator with high residence time (2 seconds) in the secondary chamber, good temperature control, and a cyclone separator is shown in the photo. The cyclone separator is a funnel-shaped device that creates a vortex to remove coarse particles from the gas. The vortex spirals downward carrying most of the coarse particles. As the gas reaches the conical section at the bottom, it turns and moves upward to exit. The dust particles fall and are collected in a hopper below.

16. A pathological waste incinerator or crematory with good temperature control operates above 850ºC and has a dust removal system. Automatic systems control the auxiliary burners especially in the secondary chamber burner. Combustion air is regulated using computer-controlled dampers to supply the required volume of air to maintain optimal process conditions. The incinerator has a refractory lining but is often covered with a metal casing.



18 & 21. Air Pollution Control Devices: In a dry or semi-dry scrubber, sorbent material is added into the gas stream to react with the acid gases formed in the incinerator. A baghouse filter or other dust removal device then captures the reaction products, excess sorbent and other particulates in the gas. Alkaline material (such as soda ash) or activated carbon is commonly used. The photo shows a dry scrubber with carbon injected into the gas stream pneumatically, followed by a baghouse filter system.

19. Air Pollution Control Devices: A wet scrubber uses water or an alkaline solution to remove particulates and acid gases from the exhaust gas. The device may use a set of spray nozzles at the top of the scrubber tower to release droplets of water that impact the particles as the gas moves upwards towards the exit of the scrubber tower. Some wet scrubbers may use a packed bed or a series of horizontal impingement plates to increase contact between the water or alkaline solution and the gas.

ANNEX C

Emission Factors for Different Combustion Methods for Healthcare Waste

#	Combustion Method	Emission Factor (ug TEQ/tonne)	Emission Factor (ug TEQ/tonne)
		AIR	**RESIDUE**
1	Open burning	6,600	600
2	Small box-type batch incinerator with no afterburner	40,000	200
3	Small box-type batch incinerator with no afterburner but used only for burning cardboard boxes with non-PVC syringes	330	200
4	Single-chamber metal incinerator with no afterburner	5,900	200
5	Drum or barrel incinerator	4,900	200
6	Multi-chamber excess air incinerator	3,600	20
7	Dual chamber incinerator with an afterburner and very low residence time (<1 second) in the secondary chamber	3,500	64
8	Tubular incinerator with two burners (800-1000ºC)	2,600	200
9	Dual chamber controlled air incinerator with low residence time (between 1 to 2 seconds) in the secondary chamber but good temperature control (primary chamber 700-900ºC, secondary chamber 870-1300ºC)	1,400	20
10	Dual chamber incinerator with low residence time, poor temperature control (primary chamber goes below 650ºC, secondary chamber goes below 750ºC) but gas goes through an alkaline wash – residue accounts only for bottom ash	1,300	300
11	Rotary kiln incinerator operating at low temperatures (700ºC) and low residence times (1 sec) in the secondary chamber, with minimal pollution control	1,000	300
12	Dual chamber pathological waste incinerator or crematory with afterburner, poor temperature control and no pollution control	970	1
13	General batch type incinerator with good residence time, good temperature control, and electrostatic precipitator or baghouse filter	525	920
14	Dual chamber controlled air incinerator with high residence time (2 seconds) in the secondary chamber, good temperature control, and a cyclone separator	270	920
15	Rotary kiln incinerator operating at high temperatures (900ºC) and high residence time (3 seconds) in the secondary chamber with minimal pollution control	130	60
16	Pathological waste incinerator or crematory with good temperature control (above 850ºC), no burning of plastics, and dust removal (filter or cyclone)	110	28
17	Dual-chamber controlled air incinerator with high residence time (2 seconds) in the secondary chamber, very good temperature control (870-980ºC in the primary chamber, 980-1100ºC in the secondary chamber), heat-recovery boiler and baghouse filter	100	64

18	Dual chamber controlled air incinerator with high residence time (2 seconds) in the secondary chamber, very good temperature control, and a dry scrubber	77	920
19	Dual chamber controlled air incinerator with high residence time (2 seconds) in the secondary chamber, very good temperature control, and a wet scrubber	13	64
20	State-of-the-art pathological waste incinerator with optimal combustion control and sophisticated air pollution control	4	28
21	Dual chamber controlled air incinerator with high residence time (2 seconds) in the secondary chamber, very good temperature control, and a dry scrubber with activated carbon injection	2	150
22	High technology, continuous, computer controlled incinerator with high turbulence and very high residence time (at least 2 seconds) in the secondary chamber, very good temperature control (primary chamber at 850ºC or higher including during feeding of waste, secondary chamber operating at 1100ºC), and sophisticated air pollution control	1	150

Emission Factors for Hazardous Waste Incineration

#	**Incinerators for Hazardous Chemical Waste (such as laboratory solvents, expired drugs, cytotoxic agents, etc.)**	**Emission Factor (ug TEQ/tonne)**	**Emission Factor (ug TEQ/tonne)**
		AIR	**RESIDUE**
23	Low technology combustion, small (< 500 kg/hr) and simple furnaces operating in batch mode, no air pollution control system	35,000	9,000
24	Controlled combustion with minimal air pollution control	350	900
25	Controlled combustion with good air pollution control	10	450
26	High technology hazardous waste incinerator with sophisticated air pollution control system, and shown to meet a dioxin/furan emission limit of 0.1 ng I-TEQ/Nm^3 at 11% O_2	0.75	30

References

1	Air emission factor based on emission factor for open burning of agricultural waste with PVC plastics from Ikeguchi T., Tanaka M., "Experimental Study of Dioxin Emission from Open Burning Simulation of Selected Wastes," *Organohalogen Compounds* 41, 507-10 (1999); Residue emission factor based on uncontrolled domestic waste burning residue emission factor in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
2	Based on Class 1 (Uncontrolled batch type combustion, no air pollution control) in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
3	Air emission factor based on average of two tests conducted on the De Montfort incinerator from WHO website "Environmental impact of incineration" (study conducted in 2003) http://www.who.int/immunization_safety/waste_management/update/en/index5.html; residue emission factor is based on Class 1 in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.

4	Air emission factor based on average of two tests conducted on the SICIM incinerator from WHO website "Environmental impact of incineration" (study conducted in 2003) http://www.who.int/immunization_safety/waste_management/update/en/index5.html; residue emission factor is based on Class 1 in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
5	Air emission factor based on dioxin emissions for the steel barrel burning of municipal waste with 7.5% PVC from Gullett B., Lemieux, P., Lutes, C., Winterrowd, C., Winters, D., "PCDD/F Emissions from Uncontrolled Domestic Waste Burning," *Organohalogen Compounds* 4127-30 and 157-160 (1999), and Gullett, B., Lemieux, P., Lutes, C., Winterrowd, C., Winters, D., "Emissions of PCDD/F from uncontrolled, domestic waste burning," *Chemosphere* 43: 721-725 (2001); Residue emission factor based on Class 1 (Uncontrolled batch type combustion, no air pollution control) in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
6	Air emission factor based on the average of MWI-11 and MWI-12 in A. Hoyos, et al., Chemosphere, 73, S137-S142 (2008); residue emission factor based on Class 2 (Controlled, batch type combustion, no or minimal air pollution control) in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
7	Air emission factor based on the average of a dual chamber (controlled air) incinerator with 0.25 second residence time in Table 3 of D. Randall and B. Hardee, "Emission Factors for Medical Waste Incinerators (MWI's)," EPA Contract No. 68-01-0115, ESD Project No. 89/02 MRI Project No. 6504-08, EPA background document, April 8, 1996, and Class 2 in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005; residue emission factor based on Class 2 in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
8	Air emission factor based on MWI-6 in A. Hoyos, et al., Chemosphere, 73, S137-S142 (2008); residue emission factor based on Class 1 in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
9	Air emission factor based on an average of the following: (A) MWI-7 in A. Hoyos, et al., Chemosphere, 73, S137-S142 (2008); (B) Emission factor for Type III (medical waste) in Alvim Ferraz et al., Arch. Environ. Contam. Toxicol., 44, 460-466 (2003); (C) Emission factors adjusted to TEQ from "Evaluation Test on a Hospital Refuse Incinerator at Saint Agnes Medical Center, Fresno, CA," CARB Report ARB/SS-87-01, California Air Resources Board, January 1987; (D) "Evaluation Re-Test on a Hospital Refuse Incinerator at Sutter General Hospital, Sacramento, CA," CARB Report ARB/ML-88-026, California Air Resources Board, April 1988; (E) Air emission factor based on the average of AP-42 for 0.5 second residence time in section 2.3 of "Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources," AP-42, fifth edition, US EPA, January 1995. Residue emission factor based on Class 2 in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
10	Based on the averages in H. Fielder, "Thailand Dioxin Sampling and Analysis Program," UNEP Chemicals, United Nations Environment Programme, Geneva, September 2001; residue emission factor estimated assuming 200 kg ash per tonne of waste burned (UNEP Toolkit, assumption used for Class 1 medical waste incinerators).
11	Based on dioxin releases for rotary kiln burning 7.5% PVC plastic waste in Yoneda et al., Chemosphere, 46, 1309-1319 (2002).

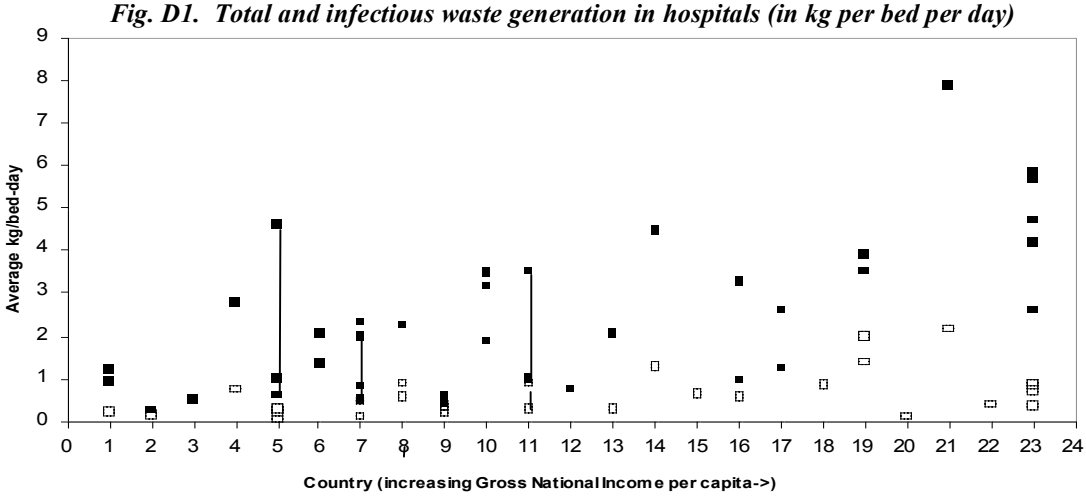
12	Air emission factor based on the average of emission data for the crematory in H. Fielder, "Thailand Dioxin Sampling and Analysis Program," UNEP Chemicals, United Nations Environment Programme, Geneva, September 2001; and the "no control" emission factor for crematoria in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005. Residue emission factor based on data for the crematory in H. Fielder, "Thailand Dioxin Sampling and Analysis Program," UNEP Chemicals, United Nations Environment Programme, Geneva, September 2001.
13	Based on Class 3 (controlled, batch type combustion, good air pollution control) in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
14	Air emission factor based on MWI-9 in A. Hoyos, et al., Chemosphere, 73, S137-S142 (2008). Residue emission factor based on Class 3 in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
15	Based on dioxin releases for rotary kiln burning 7.5% PVC plastic waste in Yoneda et al., Chemosphere, 46, 1309-1319 (2002).
16	Based on "medium control" emission factor for crematoria in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
17	Based on dioxin releases adjusted I-TEQ from "Evaluation Tests on a Hospital Refuse Incinerator at Cedars Sinai Medical Center, Los Angeles, CA," Report No. ARB/SS-87-11, California Air Resources Board, April 1987.
18	Air emission factor based on data for dry scrubber in D. Randall and B. Hardee, "Emission Factors for Medical Waste Incinerators (MWI's)," EPA Contract No. 68-01-0115, ESD Project No. 89/02 MRI Project No. 6504-08, April 8, 1996. Residue emission factor based on Class 3 in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
19	Air emission factor based on an average of the following: (A) Release data adjusted to I-TEQ in "Test data for the refuse incinerator at Stanford University Environmental Safety Facility, Stanford, CA," CARB Test Report ARB/ML-88-025, California Air Resources Board, August 1988; (B) Data for incinerator C in "Source Data and Stack Testing in California" by G. Yee, in the "Proceedings: National Workshops on Hospital Waste Incineration and Hospital Sterilization," EPA-450/4-89-002, US EPA, January 1989; and (C) Wet scrubber data in D. Randall and B. Hardee, "Emission Factors for Medical Waste Incinerators (MWI's)," EPA Contract No. 68-01-0115, ESD Project No. 89/02 MRI Project No. 6504-08, April 8, 1996. Residue emission factor based on release data adjusted to I-TEQ in "Test data for the refuse incinerator at Stanford University Environmental Safety Facility, Stanford, CA," CARB Test Report ARB/ML-88-025, California Air Resources Board, August 1988.
20	Based on "optimal control" emission factor for crematoria in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
21	Air emission factor based on data for dry scrubber with carbon injection in D. Randall and B. Hardee, "Emission Factors for Medical Waste Incinerators (MWI's)," EPA Contract No. 68-01-0115, ESD Project No. 89/02 MRI Project No. 6504-08, April 8, 1996. Residue emission factor based on Class 4 in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
22	Based on Class 4 (high technology, continuous, controlled combustion, sophisticated air pollution control) in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005.
23 to 26	Emission factors for four classes of hazardous waste incinerators in "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases," edition 2.1, UNEP Chemicals, Geneva, December 2005; residues are for fly ash only.

ANNEX D

Published Data on Waste Generation Rates

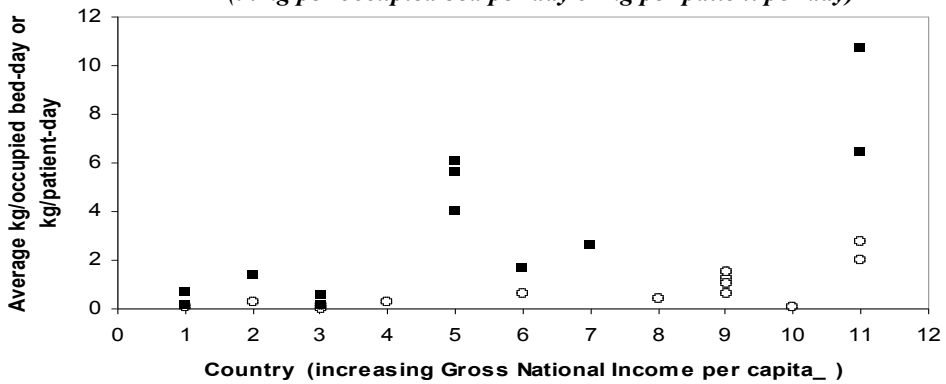
Waste generation data from other countries must be used with caution because of the wide variability even within a country and the many factors that influence the rates. The data in Figures D1 to D3 and Table D1 are provided as indicative values and should be viewed as examples. They may be useful for order-of-magnitude estimations. Even a limited survey will probably provide more reliable data on local waste generation than any estimate based on data from other countries or types of establishment.

Fig. D1. Total and infectious waste generation in hospitals (in kg per bed per day)



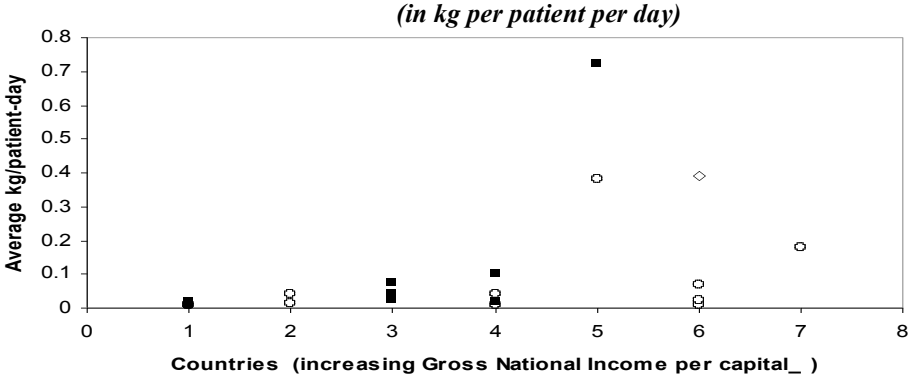
■ = total health-care waste; o = infectious waste; points represent averages; vertical lines are ranges of data. Low-income countries: 1- Bangladesh (includes clinics), 2-Cambodia, 3-Lao PDR, 4-Nigeria (poor segregation of infectious waste), 5-Vietnam, 6-Pakistan, 7-India; Middle-income countries: 8-Guyana, 9-Philippines, 10-Jordan, 11-Columbia, 12-Peru, 13-Thailand, 14-Iran (poor segregation of infectious waste), 15-Bulgaria, 16-Brazil (includes health centers and labs, poor segregation of infectious waste), 17-Turkey; High-income countries: 18-Taiwan (China), 19-Portugal, 20-Hong Kong (China), 21-Kuwait (poor segregation of infectious waste), 22-Italy, 23-United States. Source: Emmanuel (2007)

Fig. D.2. Total and infectious waste generation in hospitals (in kg per occupied bed per day or kg per patient per day)



■ = total health-care waste; o = infectious waste. Low-income countries: 1- Tanzania, 2-Vietnam, 3-Mongolia; Middle-income countries: 4-Bhutan, 5-Jordan, 6-Ecuador, 7-Peru, 8-Bulgaria, 9-South Africa, 10-Mauritius; High-income countries: 11-United States. Source: Emmanuel (2007)

Fig. D3. Total and infectious waste generation in small clinics, health centers, and dispensaries (in kg per patient per day)



■ = total health-care waste; o = infectious waste. Low-income countries: 1- Tanzania, 2-Bangladesh, 3-Pakistan, 4-Mongolia; Middle-income countries: 5-Ecuador, 6-South Africa, 7-Mauritius. Source: Emmanuel (2007)

Table D1.Total and infectious waste generation by type of facility: Low/middle-income countries (Pakistan, Tanzania, South Africa)

Type of facility	Total HCW generation	Infectious waste generation
PAKISTAN		
Hospitals	2.07 kg/bed-day (range: 1.28-3.47)	
Clinics and dispensaries	0.075 kg/patient-day	0.06 kg/patient-day
Basic health units	0.04 kg/patient-day	0.03 kg/patient-day
Consulting clinics	0.025 kg/patient-day	0.002 kg/patient-day
Nursing homes	0.3 kg/patient-day	
Maternity homes	4.1 kg/patient-day	2.9 kg/patient-day
TANZANIA		
Hospitals	0.14 kg/patient-day	0.08 kg/patient-day
Health centres (urban)	0.01 kg/patient-day	0.007 kg/patient-day
Rural dispensaries	0.04 kg/patient-day	0.02 kg/patient-day
Urban dispensaries	0.02 kg/patient-day	0.01 kg/patient-day
SOUTH AFRICA		
National central hospital		1.24 kg/patient-bed-day
Provincial tertiary hospital		1.53 kg/patient-bed-day
Regional hospital		1.05 kg/patient-bed-day
District hospital		0.65 kg/patient-bed-day
Specialized hospital		0.17 kg/patient-bed-day
Public clinic		0.008 kg/patient-day
Public community health centre		0.024 kg/patient-day
Private day-surgery clinic		0.39 kg/patient-day
Private community health centre		0.07 kg/patient-day

Sources: Pakistan data from 4 hospitals and other facilities in Karachi; Pescod and CB Saw (1998). Tanzania data based on a survey of facilities in Dar es Salaam; Christen (1996), used with permission. South Africa data from a survey of 13 hospitals and 39 clinics in Gauteng and Kwa Zulu Natal; clinics have no beds and may not be open all week; community health centres have up to 30 beds and operate 7 days a week; DEAT (2006)

ANNEX E

Some Common Units and Conversion Factors

kilogram	kg	$1x10^{3}g$	1000g
gram	g	1g	1g
milligram	mg	$1x10^{-3}g$	0.001g
microgram	µg	$1x10^{-6}g$	0.000001g
nanogram	ng	$1x10^{-9}g$	0.000000001g
picogram	pg	$1x10^{-12}g$	0.000000000001g
femtogram	fg	$1x10^{-15}g$	0.000000000000001g
attogram	ag	$1x10^{-18}g$	0.000000000000000001g

parts per million	ppm	mg/kg	µg/g	mg/l	µg/ml
parts per billion	ppb	µg/kg	ng/g	µg/l	ng/ml
parts per trillion	ppt	ng/kg	pg/g	ng/l	pg/ml
parts per quadrillion	ppq	pg/kg	fg/g	pg/l	fg/ml

ANNEX F

List of other Persistent Organic Pollutants (excluding dioxins and furans)

Common Name(s)	Chemical name	CAS Registry Number	Description
Aldrin	1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4:5,8-dimethanonaphthalene	309-00-2	Pesticide used for crops against termites, grasshoppers, and other insects
Alpha hexachlorocyclohexane (alpha HCH)	1-alpha, 2-alpha, 3-beta, 4-alpha, 5-beta, 6-beta-hexachlorocyclohexane	319-84-6	Pesticide
Beta hexachlorocyclohexane (beta HCH)	1-alpha, 2-beta, 3-alpha, 4-beta, 5-alpha, 6-beta-hexachlorocyclohexane	319-85-7	Pesticide
BDE-47; BDE-99; and other tetra- and pentabromodiphenyl ethers	2,2',4,4'- tetrabromodiphenyl ether; 2,2',4,4',5-pentabromodiphenyl ether; and other tetra- and pentabromodiphenyl ethers present in commercial pentabromodiphenyl ether	40088-47-9; 32534-81-9	Components of a flame retardant used in plastic foam
BDE-153; BDE-154; BDE-175; BDE-183; and other hexa- and heptabromodiphenyl ethers	2,2',4,4',5,5'-hexabromodiphenyl ether; 2,2',4,4',5,6'-hexabromodiphenyl ether; 2,2',3,3',4,5',6-heptabromodiphenyl ether; 2,2',3,4,4',5',6-heptabromodiphenyl ether; and other hexa- and heptabromodiphenyl ethers present in commercial octabromodiphenyl ether	68631-49-2; 207122-15-4; 446255-22-7; 207122-16-5	Components of a flame retardant used in electronic and electrical equipment
Chlordane (Octachlor, Velsicol 1068)	octachloro-4,7-methanohydroindane	57-74-9	Pesticide used against termites and other insects
Chlordecone	1,1a,3,3a,4,5,5,5a,5b,6-decachloro-octahydro-1,3,4-metheno-2H-cyclobuta[cd]pentalen-2-one	143-50-0	Agricultural insecticide
DDT	1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane	50-29-3	Pesticide used against mosquitoes
Dieldrin	(1aR,2R,2aS,3S,6R,6aR,7S,7aS)-3,4,5,6,9,9-hexachloro-1a,2,2a,3,6,6a,7,7a-octahydro-2,7:3,6-dimethanonaphtho[2,3-b]oxirene	60-57-1	Pesticide used for crops against termites and textile pests
Endrin	(1aR,2S,2aS,3S,6R,6aR,7R,7aS)-3,4,5,6,9,9-hexachloro-1a,2,2a,3,6,6a,7,7a-octahydro-2,7:3,6-dimethanonaphtho[2,3-b]oxirene	72-20-8	Pesticide used against insects, birds and mice
Heptachlor (Heptagran, Basaklor, Drinox, Soleptax, Termide, Gold Crest H-60, Velsicol 104)	1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene	76-44-8	Pesticide used against termites, grasshoppers, mosquitoes and other insects
Hexachlorobenzene (HCB)	hexachlorobenzene	118-74-1	Used against fungi, also formed during combustion

Hexabromobiphenyl (HBB, FireMaster)	hexabromo-1,1´-biphenyl	36355-01-8	Flame retardant used in synthetic fibers and plastics
Lindane (gamma benzene hexachloride, gamma-BHC, Agrocide, Aparasin, Arbitex, BBH, Ben-hex, Bentox, Celanex, Chloresene, Dvoran, Dol, Entomoxan, Exagamma, Forlin, Gallogama, Gamaphex, Gammalin, Gammex, Gammexane, Hexa, Hexachloran, Hexaverm, Hexicide, Isotos, Kwell, Lendine, Lentox, Linafor, Lindafor, Lindagam, Lindatox, Lintox, Lorexane, Nexit, Nocochloran, Novigam, Omnitox, Quellada, Silvanol, Tri-6, Vitro)	gamma,1,2,3,4,5,6-hexaclorocyclohexane	58-89-9	Insecticide
Mirex	1,1a,2,2,3,3a,4,5,5,5a,5b,6-dodecachlorooctahydro-1H-1,3,4-(methanetriyl)cyclobuta[cd]pentalene	2385-85-5	Pesticide used against ants, termites and other insects; also used as a fire retardant
Pentachlorobenzene	1,2,3,4,5-pentachlorobenzene	608-93-5	Pesticide, flame retardant, dielectric fluid
Perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride (Perfluorooctane Sulfonate or PFOS)	1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-octanesulfonate	1763-23-1; 307-35-7	Surface-active agents used for high-temperature applications and for applications in contact with strong acids or bases; used in textiles and leather products; metal plating; food packaging; fire fighting foams; floor polishes; denture cleansers; shampoos; coatings and coating additives; in the photographic and photolithographic industry; and in hydraulic fluids in the aviation industry
Polychlorinated biphenyls or PCBs	A family of compounds	1336-36-3	Fluid used in electrical transformers and

(Ascarel, Delor, Phenoclor Pyralène, Clophen, Apirolio, Fenclor, Kanechlor, Santotherm, Aroclor, Askarel , Pyroclor, Asbestol, Bakola131, Chlorextol, Hydol, Inerteen, Noflamol, Pyranol/Pyrenol, Saf-T-Kuhl, Therminol, Sovol, Sovtol			capacitors
Toxaphene (camphechlor, chlorocamphene, polychlorocamphene, chlorinated camphene)	A mixture of hundreds of chemical compounds	8001-35-2	Pesticide used against ticks, mites and other insects, as well as fish