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The International POPs Elimination Project

Fostering Active and Effective Civil Society Participation in Preparation for Implementation of the Stockholm Convention

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Estimating Releases and Prioritizing Sources in the Context of the Stockholm Convention

Dioxin Emission Factors for Forest Fires, Grassland and Moor Fires, Open Burning of Agricultural Residues, Open Burning of Domestic Waste, Landfill and Dump Fires

Pat Costner
Owltree Environmental Consulting
Eureka Springs, Arkansas, USA
pcostner@ipa.net

Red de Accion sobre Plaguicidas y Alternativas en México (RAPAM)
Texcoco, México
rapam@prodigy.net.mx

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- Encourage and enable NGOs in 40 developing and transitional countries to engage in activities that provide concrete and immediate contributions to country efforts in preparing for the implementation of the Stockholm Convention;
- Enhance the skills and knowledge of NGOs to help build their capacity as effective stakeholders in the Convention implementation process;
- Help establish regional and national NGO coordination and capacity in all regions of the world in support of longer term efforts to achieve chemical safety.

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1.0 Introduction

Uncontrolled and minimally controlled combustion processes– forest fires, grassland and moor fires, open burning of agricultural residues, open burning of domestic waste and fires at landfills and open dumps – occur in all countries to lesser or greater extents.

Most, if not all, countries that have prepared dioxin inventories using only those emission factors given in the UNEP Dioxin Toolkit have found that these uncontrolled and minimally controlled combustion processes account for the great majority of total dioxin releases, as illustrated in the summary by Fiedler (2004) of some Toolkit-based inventories: [1] [a]

- Argentina: Forest fires, grass fires and burning of agricultural residues were among the largest contributors to total dioxin releases;
- Cuba: Open burning of domestic waste was the largest contributor to dioxin releases in residues; and
- Paraguay: Open burning of domestic waste was the largest source of air releases, followed by burning of agricultural residues and forest fires, while 99 percent of releases to residues came from open burning of domestic waste and landfill fires.

The high rankings for some of these sources are not justified, based on the findings of a number of studies that apparently were not taken into consideration in the derivation of the Toolkit's emission factors.

The objective of this report is to support the preparation of dioxin release estimates that are scientifically robust and that allow sources to be prioritized and addressed for maximum benefit to public health and the environment. Toward that end, this report provides the following:

- Summary descriptions of the studies cited as the sources of each Toolkit emission factor;
- Emission factors derived in studies that are not considered in the Toolkit together with summary descriptions of the studies;
- A selection of emission factors that may be considered as most appropriate; and
- Appended examples of dioxin release estimates and source rankings that were prepared with Toolkit emission factors only and those prepared using potentially more appropriate emission factors.

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[a] In contrast, the dominant dioxin sources in the European Union are pesticide production (30 percent of total dioxin releases), followed by municipal waste incinerators (20 percent), and accidental fires involving buildings, vehicles, etc. (19 percent). [Quass, U., Fermann, M., 1997. Identification of Relevant Industrial Sources of Dioxins and Furans in Europe (The European Dioxin Inventory). Final Report No. 43, Essen, Germany: Landesumweltamt Nordrhein-Westfalen, Germany; and Wenborn, M., King, K., Buckley-Golder, D., Gascon, J., 1999. Releases of Dioxins and Furans to Land and Water in Europe. Final Report. Report produced for Landesumwaltamt Nordrhein-Westfalen, Germany, on behalf of European Commission DG Environment. September 1999.]

2.0 Inventories of Unintentionally Produced Persistent Organic Pollutants

For Parties to the Stockholm Convention, one of the first steps toward meeting the Convention's goal of continuously minimizing and, where feasible, eliminating releases of unintentionally produced organic pollutants (UPOPs) is the preparation of an inventory of UPOPs sources and the estimation of releases from those sources. This inventory is a critical component in the action plan that is specified under Article 5 of the Convention, which obligates each Party to develop an action plan that is *"designed to identify, characterize and address the release"* of UPOPs listed in Annex C: [2]

- polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF), commonly referred to collectively as "dioxins";
- polychlorinated biphenyls (PCB), and
- hexachlorobenzene (HCB).

More specifically, each Party's action plan must include the following information: [3]

> *"An evaluation of current and projected releases, including the development and maintenance of source inventories and release estimates, taking into consideration the source categories identified in Annex C;"*

2.1 UPOPs Inventories and Resource Allocations

Once their inventories[b] are compiled, Parties can prioritize their UPOPs sources and devise plans detailing the actions they will take in order to continuously minimize and/or eliminate UPOPs releases within their borders. Parties are most likely to focus their efforts on sources identified in their inventories as having the highest releases. They may take actions such as modifying and/or establishing policies, laws and regulations, enforcing such laws and regulations, establishing and conducting education campaigns, etc. Clearly these and other efforts to minimize and eliminate UPOPs releases will require mobilizing and/or redirecting both public and private resources.

UPOPs sources that are identified in inventories and, subsequently, in action plans as high release, high priority sources are most likely to attract and/or be eligible for –

- development assistance such as funding by foundations (e.g. UN Foundation), bilateral arrangements, private sector donors and non-governmental organizations (NGOs); and
- other multilateral financing mechanisms such as the Global Environment Facility, the World Bank, etc.

Access to such economic assistance will be lost and scarce public and private sector resources will be misallocated when 1) important UPOPs are not identified and included in inventories and action plans, and 2) sources are not appropriately prioritized because UPOPs releases are substantially under- and/or overestimated. At the same time, the costs of impacts on public health and the environment of unabated releases of UPOPs from important sources will continue to escalate. Inventories are clearly major factors in determining how and to what extent resources are accessed, obtained and allocated.

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[b] UPOPs inventories are commonly considered as including both sources and release estimates.

2.2 Elements of UPOPs Inventories

UPOPs inventories consist of three fundamental elements: sources, activity levels, and emission factors.

2.2.1 Sources

The United Nations Environment Programme (UNEP) has listed many, but by no means all, sources of dioxins in the three versions of its "Dioxin Toolkit". [4,5] [6] [c] There is no complete list of sources for any of the targeted UPOPs nor is such a list likely to be compiled in the near future since new sources are still being discovered.

In order to provide Parties to the Stockholm Convention with the means for identifying sources not listed in the Toolkit, it was agreed during plenary at INC7 that a source identification strategy was to be included in the second edition of the Dioxin Toolkit. Unfortunately, this agreement was not honored. The explanation given for this failure is that the International Council of Chemical Associations (ICCA) *"does not see a need to include such a strategy."* [7] [d]

2.2.2 Activity Levels

With appropriate reporting requirements, Parties will have activity levels of high to medium confidence for point sources, such as specific facilities. Such activity levels include, for example, the quantities of a product produced per year, amount of waste burned per year, etc., for a facility or for all such facilities in a country or region.

In contrast, activity levels for uncontrolled and minimally controlled combustion processes such as open burning of household waste, landfill and dump fires, forest fires, open burning of agricultural residues, etc., are most often based on very broad, poorly documented assumptions. As a consequence, activity levels for these processes have very low confidence.

2.2.3 Emission Factors

The term *"emission factor"* is used to mean the quantity of a UPOP that is released per unit of activity. Emission factors are specific to each receiving medium (air, water, land, residues, and products) so several emission factors are necessary for determining total releases from most sources. For example, an air emission factor**,** a residue emission factor , and, in some cases, a water emission factor and a product emission factor are required to estimate total releases of UPOPs from a waste incinerator.

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[c] For example, the Toolkit identifies only a very short list of sources in the industrial sectors that produce chemicals and pesticides. Hundreds of these substances are known or suspected to be accompanied by dioxin formation during their manufacture. All have chlorine as part of their molecular structure or otherwise include chlorine and/or chlorine-containing chemicals in their production processes.

[d] The comment referred to here by the Secretariat was actually a comment submitted jointly by the World Chlorine Council (WCC) and the ICCA (see UNEP/POPS/COP.1/9). On their website, the WCC acknowledges, *"Dioxins can be formed in chemical processes where the element chlorine is involved"* *(*see World Chlorine Council, 1998. Dioxins and Furans in the Chemical Industry. http://www.eurochlor.org/chlorine/issues/dioxins.htm)

To date, few studies have derived emission factors for UPOPs other than the dioxins[e]. Further, the dioxin emission factors that have been derived are predominantly for air releases from point sources such as incinerators.

As indicated by its title, the UNEP Toolkit is limited to dioxins and presents only dioxin emission factors. Most of the Toolkit emission factors are derived from studies in the European Union, the United States, and other industrialized countries because there have been relatively few studies of dioxin sources in developing countries and countries with economies in transition.

Using the Toolkit emission factors to estimate dioxin releases from sources in developing countries and countries with economies in transition can overestimate releases from some sources and underestimate releases from others. Indeed, this can also be true for industrialized countries. For example, the U.S. found the total dioxin release to air from municipal waste combustors in the U.S. was 6.8 times higher when calculated using Toolkit emission factors than when calculated using values measured in the U.S., and the total dioxin release to air from hospital waste incinerators was 80 times higher when Toolkit emission factors were used. [8]

2.3 Uncertainties of Inventories

Dioxin inventories must be regarded as “works in progress,” since much of the data used in their preparation have relatively high uncertainties. Some of the sources of uncertainty in dioxin inventories include uncertainties related to activity levels as well as those related to sampling and analysis, as pointed out by Horie (2001). [9]

With the often high degree of uncertainty of activity levels, release estimates and source identification, the prioritization of sources can also be highly uncertain and error-prone. This is especially true for uncontrolled and minimally controlled combustion processes such as forest fires, burning of agricultural residues, open burning of household waste, and landfill/dump fires for which both emission factors and activity levels generally have low confidence.

Increased capacity in developing countries and countries with economies in transition will support more thorough source identification and more accurate release estimates. In the interim, all Parties need access to dioxin emission factors that are as scientifically robust and appropriate as possible. This report is intended to fulfill that need with respect to forest fires, burning of agricultural residues, open burning of household waste, and landfill/dump fires.

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[e] This report follows the common convention of using the terms “dioxin” or “dioxins” to include both the polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans.

3.0 OPEN BURNING – Forest Fires, Grassland and Moor Fires, Open Burning of Agricultural Residues, Open Burning of Domestic Waste, Landfill and Dump Fires

A wide range of emission factors has been derived and published for these sources. This broad selection gives considerable latitude in estimating releases of dioxins from each of these sources and, ultimately, in identifying the dominant sources – those sources that are prioritized for elimination and/or reduction and, as such, are most eligible for funding.

3.1 Forest Fires, Grassland and Moor Fires

3.1.1 UNEP Dioxin Toolkit

All three versions of the UNEP Dioxin Toolkit [f] present an air emission factor of 5 ng TEQ/kg for forest fires. [g] In the 2001 and 2003 Toolkits, this emission factor was said to be based on studies of wood combustion in household stoves and fireplaces that were carried out in the Netherlands and Germany more than a decade ago. In the 2005 Toolkit, this same air emission factor was said to be based on the study by Ikeguchi and Tanaka (1999) in which leaves were burned in a furnace under conditions simulating open burning. [10] All three versions of the Toolkit gave the following reason for relying on these studies: *"No data were found that give direct measurements of PCDD/PCDF released from forest fires."* [4, 5, 6]

The Toolkit presents an emission factor for releases to land from forest fires of 4 ng TEQ/kg but cites no studies to support this value.

Studies in which scientists have made direct measurements of dioxin releases from forest fires are described below. Emission factors derived from these studies are markedly lower than those presented in the Toolkit, as illustrated in Figures 1 and 2.

3.1.2 Australian Studies

Attempting to identify the source of elevated dioxins in soils in Queensland, Australia, Prange et al. (2003) examined soils and sediments following forest fires but *"did not identify an increase in ∑PCDD/Fs or OCDD after the combustion process."* They concluded that *"forest fires are not a source of PCDD/Fs, rather they are a process for the redistribution of PCDD/Fs from existing sources and precursors".* [11] In support of this conclusion, forest ecosystems are known to capture and sequester airborne dioxins [12] and other semi-volatile compounds.[13, 14] For example, Horstmann and McLachlan (1998) found that deposition in forests of airborne dioxins and PCBs can be enhanced by a factor of up to 10 compared to a nearby non-forested area exposed to the same aerial gaseous or particle-bound dioxin and PCB concentrations.[15] More recently, Su and Wania (2005) report that *"forests may reduce concentrations* [of dioxins and related substances] *in air, ocean, and freshwater at the expense of increased concentrations in forest soils …"* [16]

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[f] The UNEP Dioxin Toolkit exists in three versions: the 2001 draft version, the 2003 first edition and the 2005 second edition.

[g] For consistency and ease of comparison, emission factors presented in the UNEP Dioxin Toolkit as well as in the scientific studies and reports cited in this paper are given in the same units. For example, in the UNEP Dioxin Toolkit , air emission factor for forest fires are expressed in micrograms TEQ per metric tonne (μg TEQ/tonne), while the units more commonly used in the scientific literature, nanograms TEQ per kilogram (ng TEQ/kg) are used in this paper.

In 2004, the government of Australia completed the most comprehensive study to date of dioxin releases from forest fires and open burning of agricultural residues. This project, which was *"designed to measure dioxin emissions from 21 field burns and 19 laboratory tests so as to replicate closely the combustion processes of open fires in the field"*, resulted in an air emission factor of 0.5 ng TEQ/kg for forest fires (wildfires and prescribed burns) and 1.0 ng TEQ/kg for savanna fires. [17, 18]

These and related air emission factors were based on field data that were *"consistent across 20 measurements at different sites across Australia."* Another important finding of the study by Meyer et al. (2004) is as follows: [17]

> "*Laboratory tests do not adequately simulate the combustion processes occurring in the field … The key difference between field and laboratory emissions may be the duration for which the smoke plume remains at high temperature. In field burns, air entrained into the smoke plume rapidly cools to temperatures that will not support the heterogeneous reactions required for dioxin synthesis."*

In further addressing the Australian study, Ivory and Mobbs (2004) noted as follows:[19]

> *"Dioxin emissions from the laboratory tests were up to ten times higher than those from field fires but were comparable to other laboratory tests. It is thought that the key difference between field and laboratory emissions may be the time that the smoke in laboratory burns remains at high temperature."*

3.1.3 Canadian Studies

Tashiro et al. (1990) published one of the first studies of dioxin formation during forest fires. After analyzing the air, soil and ash from controlled forest fires in Canada, they concluded that atmospheric deposition, not forest fires, was the contributing source of dioxins.[20] In a follow-up study, Clement and Tashiro (1991) reported an average concentration of 20 pg/m^3 total dioxins in forest fire smoke.[21]

Van Oostdam (1995) found no detectable dioxins in three soil samples and four ash samples taken just after a forest fire in British Columbia, Canada. [22] In another study in Canada, Ikonomou et al. (1999) reported that *"data do not show levels high enough and/or distinct patterns that would suggest that the sediments in the streams examined have been impacted by PCDDs/Fs produced from the forest fires."* [23] Gabos et al. (2001) reached a similar conclusion after finding very low concentrations of dioxins in sediments following extensive forest fires in Canada.[24]

3.1.4 Japanese Study

Ikeguchi and Tanaka (1999) burned trees and leaves in a metal furnace under conditions simulating open burning. The air emission factor derived from their results is 4.6 ng TEQ/kg. [10]

3.1.5 Korean Study

Kim et al. (2003) found an average dioxin concentration of 2.5 ng TEQ/kg in ash from forest fire sites. This level was 2.5-fold higher than those at a control site.[25]

3.1.6 New Zealand Study

Buckland (1994) found no marked differences between dioxin levels in soil samples collected from each of three burnt and three unburnt areas in national parks in New Zealand, six weeks after large-scale brush fires.[26]

3.1.7 Spanish Study

Martinez et al. (2000) analyzed vegetation and soils in forest fire areas in Spain and concluded that *"natural fires seem not to be an important source of dioxin-like compounds."* [27]

3.1.8 U.S. Study

Gullet and Touati (2003) burned live shoots and needle litter from the forest floor on a metal platform in an enclosed, controlled-burn facility and derived an air emission factor of 19 ng TEQ/kg.[28] Citing this study, the U.S. Environmental Protection Agency (US EPA) used an air emission factor of 2 ng W-TEQ/kg in estimating dioxin releases from forest fires in the most recent U.S. inventory.[29]

3.1.9 Summary – Forest Fires, Grassland and Moor Fires

A considerable body of scientific evidence, including direct measurements, indicates that dioxin releases from forest fires are relatively low, with an air emission factor of some 0.5 ng TEQ/kg or less. Such releases are attributed largely to the capture of airborne dioxins and dioxin precursors in forest leaves and bark and the subsequent deposition and accumulation of these substances in forest soils.

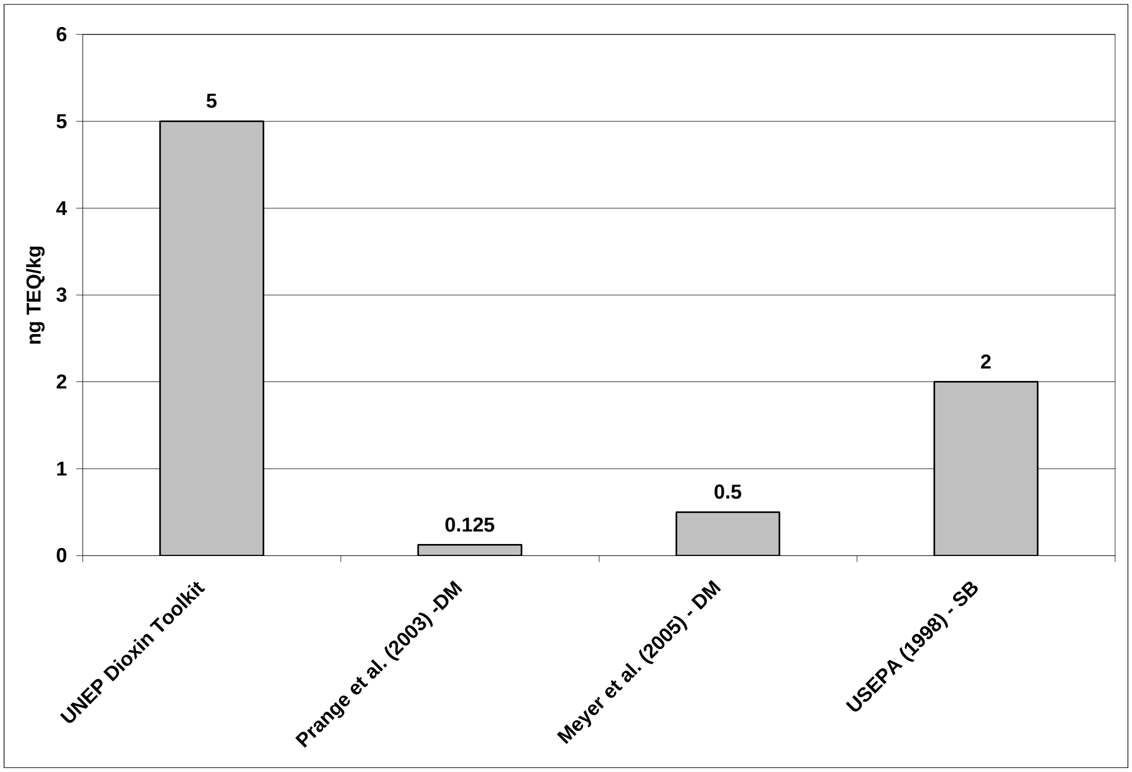

Figure 1: Forest fires – emission factors for releases to air (DM = direct measurements of forest fire; SB = surrogate burn in enclosed facility)

As shown in Figure 1, the Toolkit's air emission factor for forest fires is far larger than those based on measurements made during actual forest fires. Moreover, it is 2.5 times larger than the factor derived by the U.S. Environmental Protection Agency (1998) from many of the same studies used in the Toolkit's derivation. [30]

The Toolkit presents an emission factor for releases to land from forest fires of 4 ng TEQ/kg but cites no studies to support this value. However, as discussed earlier, studies by Buckland (1994) [26] and Von Oostdam (1995)[22] indicate an emission factor for releases to land that is at or very near zero, which is supported by the findings of Ikonomou et al. (1999)[23] and Martinez et al. (2000). [27]

Kim et al. (2003) measured dioxin levels in soils at forest fire sites that were, on average, 2.5-fold higher than those at a control site. In addition, they reported an average dioxin concentration of 2.5 ng TEQ/kg in ash from the forest fires, [25] as compared to 1.2 ng TEQ/kg reported by Martinez et al. (2000) in a sample that was mostly ash. [27] In contrast, the Toolkit emission factor for releases to land is based on a *"concentration in ash of 200 ng TEQ/kg,"* with no studies cited to support this value.

Using the ash concentration reported by Kim et al. (2003) and Martinez et al. (2003) and the Toolkit's assumption of *"an average ash production of 2 % of mass burned"* results in emission factors for dioxin releases to land of 0.05 ng TEQ/kg and 0.02 ng TEQ/kg, respectively, as shown in Figure 2.

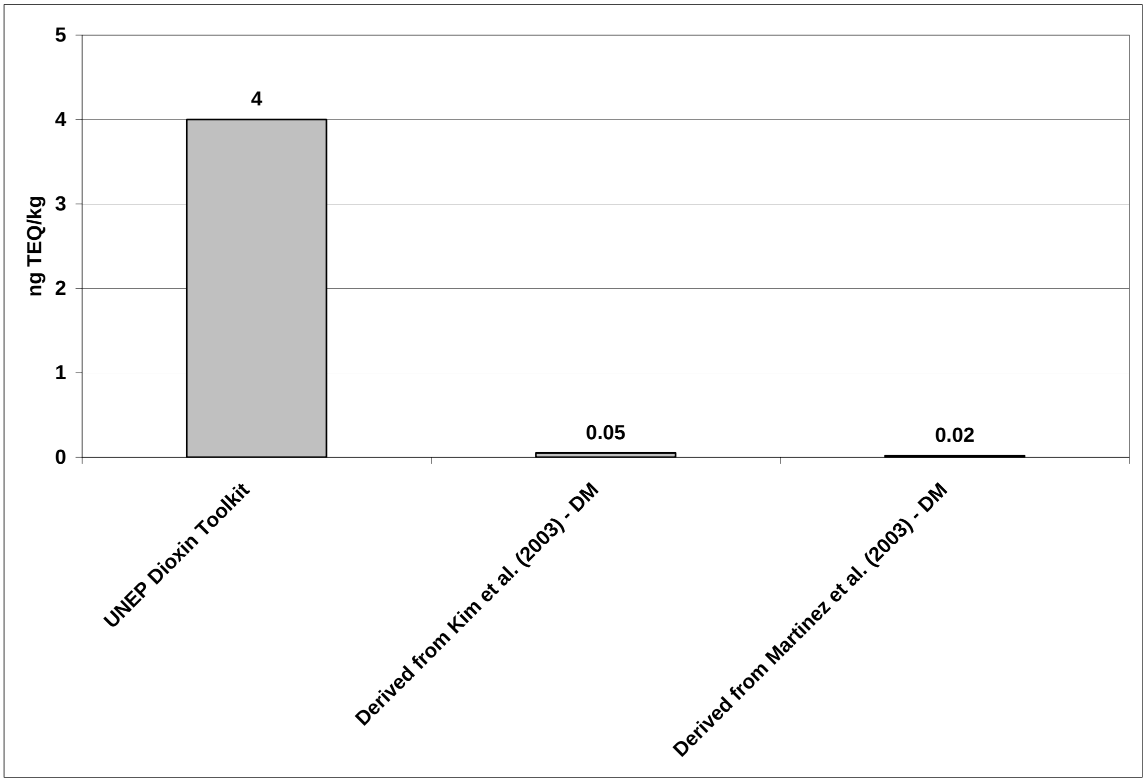

Figure 2: Forest fires – emission factors for releases to land (DM = direct measurement of forest fire ash)

3.2 Open Burning of Agricultural Residues

3.2.1 UNEP Dioxin Toolkit

For open burning of agricultural residues, the 2001 Toolkit gives an air emission factor of 30 ng TEQ/kg. [4] The 2003 and 2005 editions of the Toolkit present air emission factors of 0.5 ng TEQ/kg when clean residues are burned under favorable conditions and 30 ng TEQ/kg when residues have been exposed to pesticides and/or combustion conditions are unfavorable. [5, 6]

The Toolkit's air emission factor of 30 ng TEQ/kg is attributed to a study by Ikeguchi and Tanaka (1999) in which combustion was carried out in a furnace under conditions intended to simulate open burning. The air emission factor of 0.5 ng TEQ/kg is based on a study by Gullett and Touati (2002), in which residues were burned on a metal grid in an enclosed facility intended to simulate open field burning.

All three versions of the Toolkit present an emission factor for releases to land of 10 ng TEQ/kg. No studies are cited to support this value.

3.2.2 Australian Studies

Meyer et al. (2004; 2005) reported an air emission factor of 0.8 ng TEQ/kg for burning sugar cane in fields, which was about three times less than the air emission factor determined in a facility intended to simulate open burning conditions. No information was given on the use of pesticides, chlorinated or otherwise. [17, 18] However, more than thirty different pesticides are used in sugar cane farming in Australia. Atrazine, one of those most commonly used, is a chlorine-containing pesticide. [31]

3.2.3 Danish Study

Schleicher et al. (2002) reported an air emission factor of 5.3 ng TEQ/kg when straw was burned in a small, poorly-controlled boiler with no flue gas cleaning. [32]

3.2.4 German Studies

Vierle et al. (1999) and Launhardt et al. (2000) found a clear relationship between the chlorine content of biogenic fuels, including straw, and dioxin emissions using various combustion systems. [33, 34]

3.2.5 Japanese Study

Ikeguchi and Tanaka (1999) burned bundles of straw and rice husks on a metal grid in an enclosed facility under conditions intended to simulate open burning. They reported air emission factors of 20.2 ng TEQ/kg with the straw and 67.4 ng TEQ/kg with rice husks. [10]

3.2.6 U.K. Studies

Guyton et al. (1986) found no detectable levels of airborne dioxins during sugar cane field burning,[35] and Walsh (1994) noted no increase in soil dioxin levels following controlled straw field burning tests in the United Kingdom. [36] Chaggar et al. (1998) presented data showing higher air emission factors for biomass, such as straw, that typically has higher chlorine content.[37]

3.2.7 U.S. Studies

Gullett and Touati (2002) burned field residues of wheat (spring and winter) and rice on a metal grid in an enclosed facility intended to simulate open field burning. They reported air emission factors of 0.337-0.602 ng TEQ/kg and 0.537 ng TEQ/kg with, respectively, spring and winter wheat and rice field residues. [38] In this study as well as in a more detailed description given in Gullett and Touati (2003), an air emission factor of 0.5 ng TEQ/kg was regarded as appropriate for both residues. The authors specified that the spring wheat had been treated with non-chlorinated herbicides but gave no information on the other residues. [39]

3.2.8 Summary – Open Burning of Agricultural Residues

The Toolkit's air emission factor of 0.5 ng TEQ/kg for agricultural residues that are *"not impacted"* is similar to the values reported by Gullett and Touati (2003) [39] and Meyer et al. (2004; 2005), [17,18] as shown in Figure 3. However, no studies were found to support the Toolkit's air emission factor of 30 ng TEQ/kg for burning agricultural residues that are *"impacted"* or burned under *"poor conditions"*.

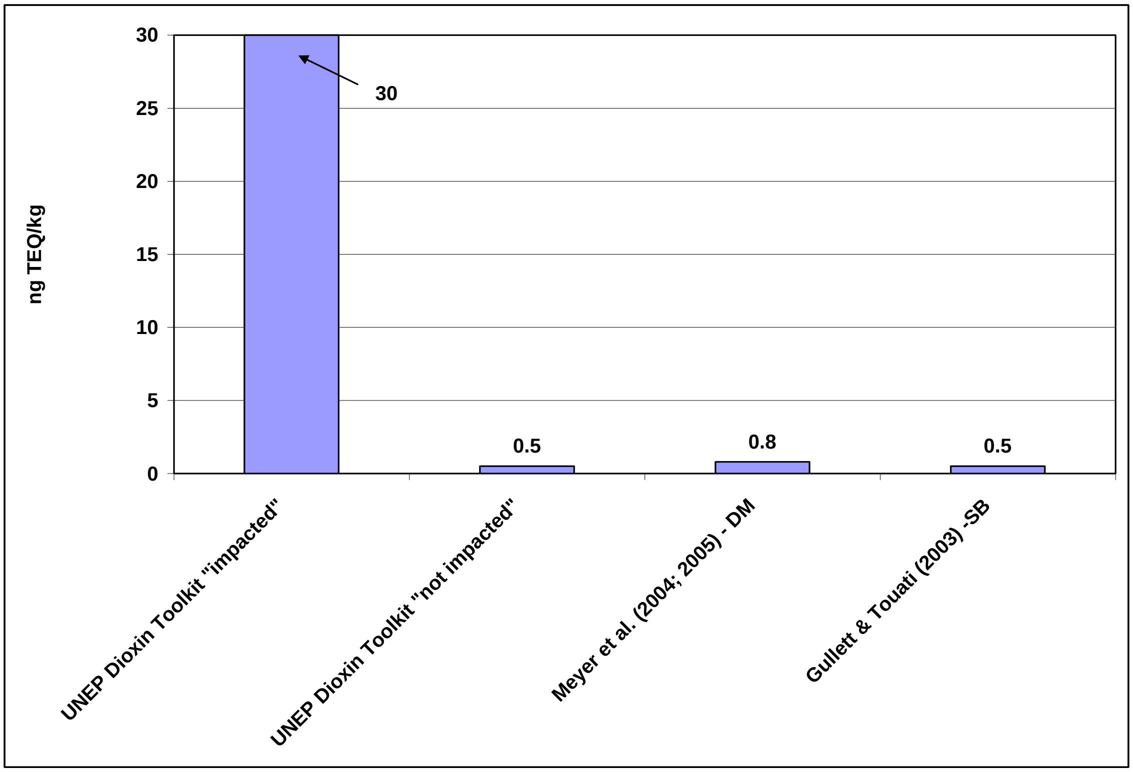

Figure 3: Open burning of agricultural residues – emission factors for releases to air (DM = direct measurement of agricultural residue burning; SB = surrogate burn in enclosed facility)

The Toolkit cites no studies to support an emission factor for releases to land of 10 ng TEQ/kg for burning agricultural residues. No studies that present an emission factor for releases to land were found during the preparation of this report. However, it is not plausible that dioxin releases to land are 20 times greater than releases to air, as indicated by the Toolkit's emission factors.

Results from experimental burning of leaf litter and soil by Prange et al. (2003) indicate that releases to air are far greater than releases in ash and soil. [40] Consequently, more plausible emission factors for releases to land are 0.02 ng TEQ/kg and 0.05 ng TEQ/kg, as previously derived from Martinez et al. (2003) [27] and Kim et al. (2003)[25], respectively, for releases to land from forest fires. In Figure 4 below, these values are compared with that presented in the Toolkit.

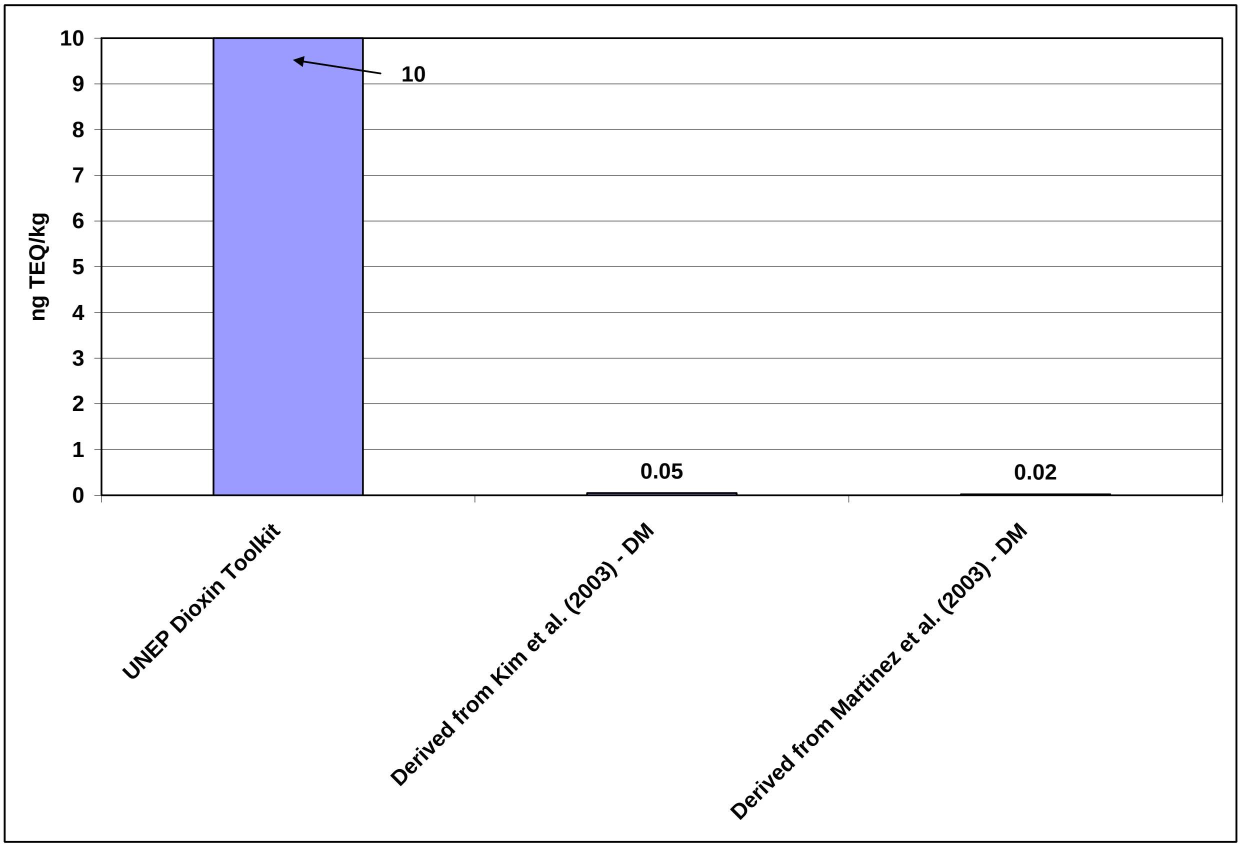

Figure 4: Open burning of agricultural residues – emission factors for releases to land (DM = direct measurement of agricultural residue burning)

It is interesting to note that Bakker and Jenkins (2003) reported that leaching by rain washing in the field reduced the chlorine content in agricultural residues. They found substantial reductions in the chlorine and alkali content of rice straw, wheat straw, switchgrass, and wood fuels by water leaching, with subsequent improvements in combustion behavior. They also concluded that leaching during sugar extraction is largely responsible for the generally low fouling rates associated with sugar cane bagasse combustion. [41]

3.3 Open Burning of Domestic Waste

> *“ Most of the world’s waste is still dumped in the open, and in most of those disposal sites waste may also be burned in the open (open burning)”.* [42]

Even in the wealthiest, most technologically-advanced countries, people burn their domestic waste in open piles, barrels, fireplaces, household heating stoves, and primitive incinerators. For example, open burning of domestic waste has been identified as the largest quantifiable source of dioxin releases to the air in the United States. [43]

3.3.1 UNEP Dioxin Toolkit

All three versions of the Toolkit give an air emission factor of 300 ng TEQ/kg for uncontrolled burning of domestic waste – burning such wastes in open piles, in barrels, and in home fires – *“where a wide range of wastes including items such as household hazardous wastes and chemicals may be burned.”* [4, 5 ,6] The studies cited in the Toolkit as the basis for this emission factor are two studies by scientists with the U.S. Environmental Protection Agency -- Lemieux (1997)[44] and Gullett et al. (1999)[45] – as well as a review by Lemieux et al. (2003).[46] As shown in Figure 3 below, the Toolkit's air emission factor, 300 ng TEQ/kg, is markedly higher than the air emission factors for domestic waste having a composition that is common to developed countries.

The Toolkit's emission factor for releases to residues, 600 ng TEQ/kg, is attributed to the study by Lemieux et al. (1997). As shown in Figure 4, this value is higher than that reported by Lemieux et al. (1997) for wastes with a polyvinyl chloride (PVC) content of 0.2 percent,[44] which is considered to be typical of U.S. domestic waste.[47] Further it is far higher than the emission factor reported by Hedman et al. (2005) when the combustible portion of Swedish domestic waste was burned.[48]

3.3.2 Belgian Study

Wevers et al. (2004) burned household waste and yard waste (trimmings and fallen leaves) in a galvanized steel drum, an oil barrel and open piles. The household waste consisted of the *"combustible fraction, a mixture of plastics, beverage cartons, paper and cardboard"* sorted from the waste collected by 15 families during one month*.* The composition of this waste was *"considered to be representative for backyard waste burning but lower in water, organic and inert material than municipal waste."* Based on their experiments, Wevers et al. (2004) reported the following air emission factors:[49]

- 4.7 – 20 ng TEQ/kg for garden waste in galvanized drums;
- 4.4 ng TEQ/kg for garden waste in an open pile; and
- 35 ng TEQ/kg for household waste in a steel oil barrel.

The higher air emission factor, 20 ng TEQ/kg, for garden waste burned in a galvanized drum was attributed to poorer combustion due to restricted air flow into the drum. The dioxin content of the ashes was not determined for any of the experiments.

Using wood stoves for household heating, Wevers et al. (2003) reported mean air emission factors of 24.4 ng TEQ/kg and 350 ng TEQ/kg when burning the combustible portion of household waste with untreated and treated wood, respectively.[50]

3.3.3 Swedish Study

In a study at the University of Umea in Sweden, Hedman et al. (2005) burned garden waste and refuse derived fuel ("*municipal waste where the combustible fractions (e.g. paper, textile and soft plastics) had been mechanically sorted out from noncombustible waste and decomposable material at a waste sorting plant")* in open steel barrels and on a steel plate. Their findings suggest that *"general* [air] *emission factors for PCDF and PCB may be in the range …) of 4-72 ng/kg, with a median value of 20 ng/kg (WHO-TEQ)."* They also found that dioxin levels in ash *"were usually less than 5% of the total"* dioxin releases. More specifically, these researchers reported dioxin emission factors of 16-18 ng W-TEQ/kg for releases to air and 0.3 ng W-TEQ/kg for releases to residues when burning a mixture of refuse derived fuel and garden waste.[48] The refuse derived fuel had a chlorine content ranging from 0.13 to 0.52 percent, with almost 75 percent of the chlorine attributed to the plastic fraction of the waste, which was known to contain PVC.[51]

3.3.4 Japanese Studies

Ikeguchi and Tanaka (2000) burned various household waste components in small metal "home incinerators" that appear to be no more complex than barrels with air vents and a large chimney. Among the air emission factors that were derived are the following: [52]

- 5-140 ng TEQ/kg for garden waste;
- 400-420 ng TEQ/kg for newspaper;
- 6-420 ng TEQ/kg for corrugated paper;
- 1,670-11,500 ng TEQ/kg for corrugated paper plus 5 percent PVC;
- 4,000-17,000 ng TEQ/kg for corrugated paper plus 10 percent PVC;
- 6,100-28,000 ng TEQ/kg for corrugated paper plus 20 percent PVC;
- 40 ng TEQ/kg for corrugated paper plus 5 percent polystyrene;
- 3-30 ng TEQ/kg for corrugated paper plus 10 percent polystyrene;
- 10 ng TEQ/kg for corrugated paper plus 10 percent polyethylene; and
- 3-40 ng TEQ/kg for corrugated paper plus 20 percent polyethylene.

In this study, chlorine was added to the materials burned in the form of PVC and as sodium chloride. Air emissions of dioxins were found to increase with higher chlorine levels in the materials combusted.

Nakao et al. (2005) burned a variety of materials – paper, leaves, natural wood, building materials, fiber, non-chlorine-containing plastics, chlorine-containing plastics, and copper electric wire – in a small, uncontrolled metal incinerator. No emission factors were derived. However, they found that including non-chlorine-containing plastics had no impact on dioxin releases but the addition of chlorine-containing plastics increased dioxin concentrations in flue gas and residual ash by some 60-fold, expressed as TEQ. With the further inclusion of copper wire, dioxin flue gas concentrations increased 570-fold and residual ash concentrations, more than 2,000-fold. [53]

3.3.5 U.S. Studies

In the first of a series of experiments, Lemieux (1997) burned simulated household waste [h] in steel barrels in an enclosed testing facility. The average air emission factors derived for waste with PVC content of 0.2 and 4.5 percent were 140 ng TEQ/kg and 2,654 ng TEQ/kg, respectively.[44] Based on the data from this study, the U.S. Environmental Protection Agency used an air emission factor of 140 ng TEQ/kg in the U.S. dioxin inventory in 1998. [30]

In a follow-on study at the same facility, Gullett et al. (1999; 2001) derived the following air emission factors when burning simulated household waste in a steel barrel: [45, 54]

- 14 ng TEQ/kg with no PVC;
- 79 ng TEQ/kg with 0.2 percent PVC;

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[h] The wastes are described as *"a reasonable representation of a waste stream … according to the typical percentages of various materials characterized and quantified for New York State residents."* It consisted of various kinds of paper products, plastic resins, food waste, textile/leather, wood, glass/ceramics, iron and aluminum cans, as well as wire, copper pipe and batteries (see Lemieux, 1997). This same general composition was used in all of the U.S. studies described here.

- 201 ng TEQ/kg with 1 percent PVC;
- 4,916 ng TEQ/kg with 7.5 percent PVC; and
- 734 ng TEQ/kg with no PVC but with the addition of chlorine, as calcium chloride, in a quantity equivalent to that present with 7.5 percent PVC.

Drawing on the results of earlier experiments at this facility and with additional variables including copper content, moisture levels and further combustion conditions, Gullett et al. (2000) reported air emission factors ranging from 1.7 to 6,433 ng TEQ/kg. They also found lower dioxin releases in one experiment in which wastes were burned in an open pile rather than a steel barrel. [55]

In another related study, Lemieux et al. (2000) burned simulated household waste containing 0.2 percent PVC and 4.5 percent PVC in a steel barrel in the enclosed testing facility and reported air emission factors of, respectively, 759 to 903 ng TEQ/kg and 1,230 to 5,400 ng TEQ/kg. [56] However, these values were apparently erroneously reported, given the wide disparities between them and air emission factors presented in closely related studies, including a later review paper by the same author.

In the most recent description of these and additional results from this series of experiments, Lemieux et al. (2003) reported an average air emission factor of 76.8 ng W-TEQ/kg for household waste containing 0.2 percent PVC. [46] This air emission factor is used in the most recent U.S. dioxin inventory. [57] Lemieux et al. (2003) also reported a somewhat lower air emission factor, 61 ng TEQ/kg, when household waste was burned in an open pile on a steel grate rather than in a steel barrel. In addition, they concluded, "*At moderate levels of* [chlorine]*, a statistically significant effect of waste* [chlorine] *concentration is not observed, because other more important variables have a much greater influence on the emissions of* [dioxins]." [46] However, in a detailed reanalysis of these same data, Neurath (2004) found that chlorine content and, especially PVC content, are the most important predictors of dioxin emissions from the open burning of domestic waste. **[58]**

3.3.6 Summary -- Burning Domestic Waste in Steel Barrels and Open Piles

As shown below in Figure 5, the Toolkit's emission factor for dioxin releases to air during the open burning of domestic waste is considerably higher than the emission factors reported for domestic waste containing PVC at levels that are commonly found in the domestic waste of industrialized countries. The Toolkit's emission factor for releases to residue from such waste is higher than other reported values, as shown in Figure 6.

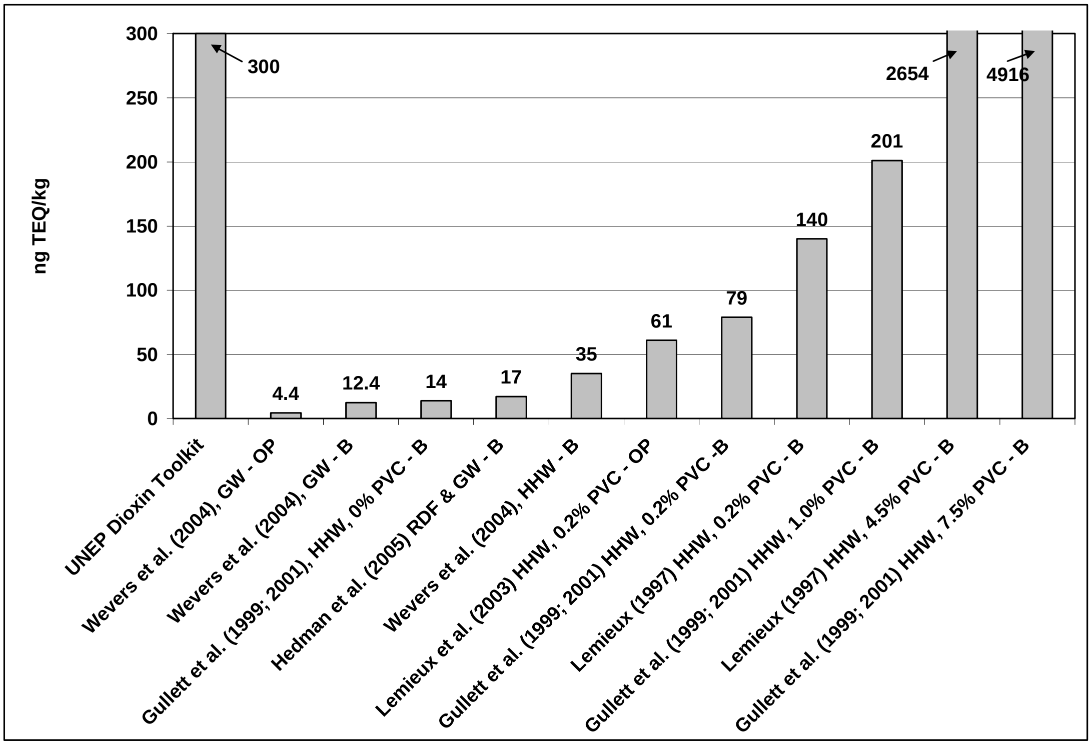

Figure 5: Burning Domestic Waste in Steel Barrels and Open Piles – Emission Factors for Releases to Air (GW = garden waste; HHW = household waste; RDF = refused derived fuel; OP = open pile; B = barrel)

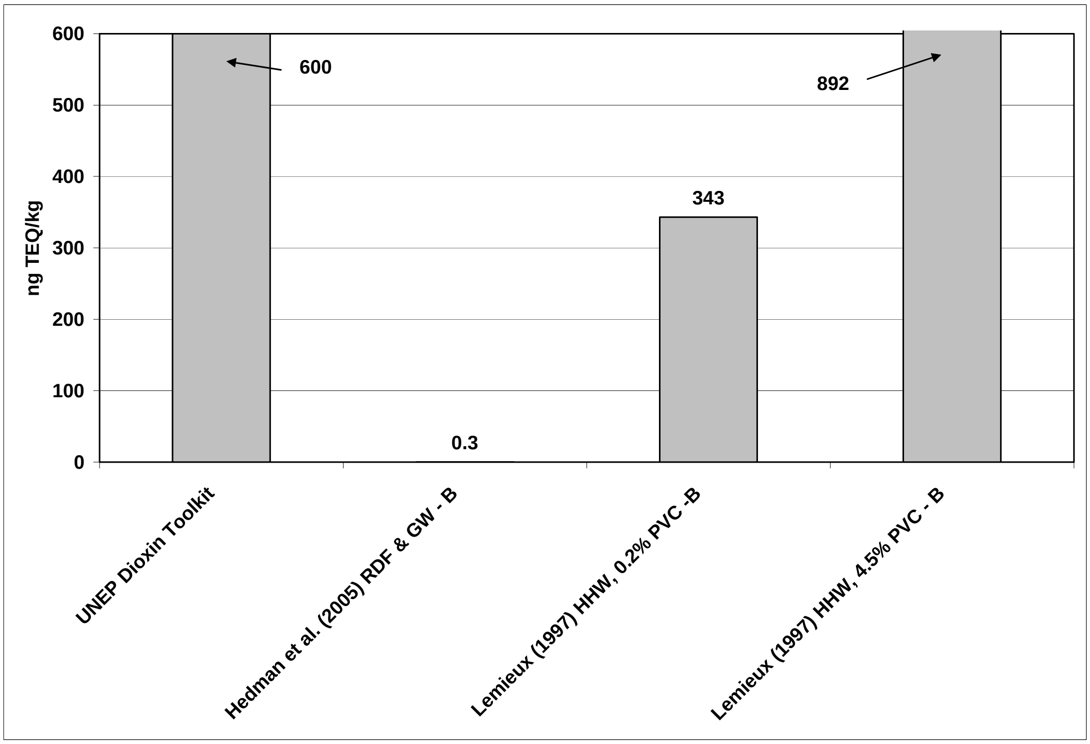

Figure 6: Burning Domestic Waste in Steel Barrels and Open Piles – Emission Factors for Releases to Residues (GW = garden waste; HHW = household waste; RDF = refuse derived fuel; OP = open pile; B = barrel)

The composition of domestic waste and the conditions of its combustion determine the extent of dioxin formation during combustion. Obviously both of these determinants vary over very broad ranges so there can be no universally applicable emission factors for dioxin releases to air, land or residues for open burning of domestic waste.

To estimate dioxin releases from open burning of domestic waste, Parties must be familiar with the waste compositions and combustion conditions that prevail in their individual countries and choose emission factors that were derived with wastes and conditions most similar to their own.

The need for more study of open burning of domestic waste is made obvious by the paucity of data in Table 1.

Table 1: Open Burning of Domestic Waste -- Dioxin emission factors for releases to air according to combustion conditions, general waste composition, and PVC content of the waste

General waste composition	Combustion conditions	PVC content					
		0 %	0.2 % or less	1 %	4.5%	7.5%	Other
Unsorted domestic waste, including glass, cans, food, etc.	Open pile		61[46]				
	Metal container (steel barrel, etc.)	14[45,54]	79-140[44,45, 54,]	201[45, 54,44]	2,654[44]	4,916[45,54]	
Combustible portion of domestic waste	Open pile						
	Metal container (steel barrel, etc.)						35[49][i]
Combustible portion of domestic waste and garden waste	Open pile						
	Metal container (steel barrel, etc.)						17[48][j]
Garden waste	Open pile	4.4[49]					
	Metal container (steel barrel, etc.)	12.4[49]					

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[i] *"The household waste was collected by 15 families during one month. Mainly the combustible fraction, a mixture of plastics, beverage cartons, paper and cardboard was used. This composition is considered to be representative for backyard waste burning but lower in water, organic and inert material than municipal waste."*

[j] *"The refuse-derived fuel (RDF) consisted of municipal waste where the combustible fractions (e.g. paper, textile and soft plastics) had been mechanically sorted out from noncombustible waste and decomposable material at a waste sorting plant."*

Despite the lack of data in Table 1, it provides potentially useful insights into choosing the most appropriate emission factor from those currently available:

- Open pile or metal container (steel barrel, etc.): In two studies, burning waste in barrels resulted in higher dioxin emissions than burning waste in open piles. This is not surprising since iron, the primary constituent in steel barrels and most other metal containers that might be used for waste burning, was found to be *"a strong promoter for PCDD/F [dioxin] formation"* by Halonen et al. (1997). [59] Iron in the metal grates and plates used as combustion platforms in open burning experiments may be promoting dioxin formation.
- Domestic waste – sorted or unsorted: Unsorted waste burned in the U.S. studies included not only combustibles but also glass/ceramic materials, food wastes, steel and aluminum cans. As noted in the Belgian and Swedish studies, burning such waste is not a common practice in those countries, or, in all likelihood, in most countries. Consequently, the emission factors from the U.S. studies may be more useful as indicators of the effects of variables, such as PVC content, than as factors for general use in estimating releases.
- Domestic waste or a mixture of domestic and yard waste: The combustible portion of domestic waste is commonly burned together with garden and yard waste. Reduced dioxin formation through such "co-firing" is supported by the findings of 1) relatively low emission factors in the Belgian and Swedish studies in which domestic and yard wastes were burned together and 2) considerably higher emission factors in the U.S. studies in which only unsorted domestic waste was burned.

At present, the emission factors from the Swedish study – 17 ng TEQ/kg for air releases and 0.3 ng TEQ/kg for releases to residues -- appear to be the most appropriate factors when, as is the common practice, the combustible portion of domestic waste with an ordinary PVC content is burned together with yard and garden waste in open piles.

3.4 Landfill and Dump Fires

Fires at landfills and dumps are common occurrences, even in the wealthiest regions of the world. For example, the most recent European Dioxin Inventory notes as follows:

> *"It is well known that in some European countries still illegal and uncontrolled dump sites for municipal solid waste exist. Such dumping sites frequently are set to fire either by autoignition or intentionally in order to increase their capacity."* [60] [61]

U.K. landfill operators surveyed by Bates (2004) estimated that, at any one time, deep seated fires are occurring at about 80 percent of landfills. Such fires are generally more difficult to identify and extinguish than surface fires. [62] In the U.S., dump and landfill fires are reported at a rate of 8,400 fires per year. In fact, in the U.S., deliberate landfill fires are an accepted practice to reduce refuse volumes and operating costs and to increase a landfill's operating life, [63] even though landfill fires have been identified as one of the largest dioxin sources in the U.S. [64]

3.4.1 UNEP Dioxin Toolkit

All versions of the Toolkit present an air emission factor of 1,000 ng TEQ/kg for landfill and dump fires. This value is said to be based on Swedish work as reported by the U.S. Environmental Protection Agency. [4,5,6] Although the original Swedish study by Persson and Bergstrom (1991) [65] was not readily available, the results of this study have been described as follows:

- According to the U.S. Environmental Protection Agency, the study reported an average emission rate of 1,000 ng Nordic TEQ/kg of waste burned. [66]
- According to the European Dioxin Inventory, the Swedish researchers carried out simulation experiments in which dioxin concentrations in the combustion gas ranged from 66 to 518 ng N-TEQ/m³. At a specific flue gas volume of 1700 m³/t, an air emission factor of about 100 – 900 ng TEQ/kg can be derived. [67]
- According to the landfill review by Bates (2004), the Swedish study estimated dioxin releases of 0.07 g TEQ per surface fire and 0.35 g TEQ per deep fire. [62]

3.4.2 Asian Studies

Minh et al. (2003) examined soils from open dumps in the Philippines, Cambodia, India, and Vietnam, where open burning was observed, and found dioxin levels in soils that were, in some cases, hundreds of times higher than soils from control sites. [68] In a related study at some of these sites, Hirai et al. (2003) determined that the emission factor for total releases (air and land) must be greater than 400 ng TEQ/kg to explain dioxin levels in soil samples at the Indian dump and greater than 4,000 ng TEQ/kg at the Cambodian dump. [69]

3.4.3 Japanese Study

In a landfill fire simulation, Hirai et al. (2005) burned refuse derived fuel (RDF) in a steel bowl filled with soil. The RDF was comprised of paper and textiles, 51.8 percent; plastics and leather, 32 percent; wood and grass, 5.3 percent; garbage, 9.5 percent; non-combustibles, 0.4 percent; and others, 1 percent. They reported emission factors for releases to air of 23-46 ng TEQ/kg and for releases to residues, 120-170 ng TEQ/kg, with 70-90 percent of the dioxins partitioned to the residues. [70]

3.4.4 Swiss Study

In Switzerland, an air emission factor of 450 ng TEQ/kg for landfill fires was based on a dioxin concentration of 15 µg TEQ/kg in the filter dust of a municipal solid waste incinerator and a dust release rate of 30 kg dust/t waste.[67]

3.4.5 Related Studies

Other studies have examined the occurrence of dioxins during or following fires at landfills and dumps but have not derived emission factors:

- Estonia: Roots et al. (2004) found dioxins in soils at a landfill to be present at background levels. [71]
- Finland: Ruokojarvi et al. (1995) measured elevated dioxin levels in the air and in unburned, burned and smouldered waste at experimental and real landfill fires. [72]
- Greece: Martens et al. (1998) also reported an elevated dioxin level in a soil sample directly impacted by uncontrolled burning at an open dump site. [73]
- Jordan: Alwai et al. (1996) found dioxin levels that ranged from 8.3 to 1,470 ng TEQ/kg in soil samples from a landfill near Amman. The homologue pattern of the sample with the highest dioxin concentration was said to be *"typical for the pyrolysis of PVC"*. [74]

- Spain: Abad et al. (2003) found dioxins at levels 19 times higher in moss samples taken near a Spanish landfill where open burning was taking place than in moss from a control site. [75]

In the European Union, Mersiowsky et al. (1999) examined four groups of PVC products – pipes, rigid foils, floorings and cables – and found that they accounted for 40 percent of PVC sent to landfills and contributed 39 percent of the chlorine in the municipal solid waste sent to landfills. More specifically, the municipal solid waste sent to landfills had a chlorine concentration of 9,000 mg/kg, of which 3,500 mg/kg was contributed by the four groups of PVC products studied. [76] Assuming that the remaining 60 percent of PVC sent to landfill has a chlorine content similar to that of the four groups of PVC products addressed in this study, then 100 percent of the PVC products sent to landfill would contribute 8,750 mg/kg of chlorine, or 97 percent of the total chlorine content of municipal solid waste sent to landfill. If this is the case, PVC accounts for the overwhelming majority of chlorine that is available for dioxin formation during landfill fires.

3.4.6 Summary -- Landfill and Dump Fires

Emission factors for fires at landfills and open dumps cover very broad ranges which depend on many, highly variable factors. As with open burning of domestic wastes, there are no universally applicable emission factors. However, the recent study by Hirai et al. (2005) presents what appears to be the most rigorous derivation of emission factors: 23-46 ng TEQ/kg for releases to air and 120-170 ng TEQ/kg for releases to residues. [70]

3.5 Findings and Recommendations

Based on the studies considered in this report, the emission factors shown below in Table 2 appear currently to have the strongest scientific support and, as such, are most appropriate for preparing release estimates in dioxin inventories.

Emission factors for forest fires, grassland and moor fires and for open burning of agricultural residues have relatively low values and narrow ranges. For forest fires, grassland and moor fires, the most appropriate emission factors are those based on measurements taken during actual fires, 0.5 ng TEQ/kg for releases to air and 0.05 ng TEQ/kg for releases to land. Similarly, the appropriate factors for open burning of agricultural residues are 0.8 ng TEQ/kg for releases to air and 0.05 ng TEQ/kg for releases to land.

Emission factors for open burning of domestic waste vary by more than a thousand-fold, as shown in Table 2. For this source category, 17 ng TEQ/kg for releases to air and 0.3 ng TEQ/kg for releases to land are, at present, the most appropriate emission factors for open burning of domestic waste when the common practice is to burn the combustible portion of domestic waste with an ordinary PVC content (~0.2 percent) together with yard and garden waste.

Studies that have derived emission factors for landfill/open dump fires are very limited. However, where the composition of the waste burned is similar to that studied by Hirai et al. (2005), [70] the means of the emission factors derived in their study can be regarded as appropriate – 34.5 ng TEQ/kg for releases to air and 145 ng TEQ/kg for releases to land.

Table 2: Dioxin Emission Factors with Strongest Scientific Support to Date

	Emission factor for releases to air	**Emission factor for releases to land**	**Emission factor for releases to residues**
	ng TEQ/kg		
Forest fires, grassland and moor fires	0.125-0.5	0.02-0.05	
Agricultural residues, open burning	0.5-0.8	0.02-0.05	
Domestic waste, open burning			
No PVC content, 0%	4.4-14		0.3
Moderate PVC content, 0.2% or less	17-79		0.3-343
High PVC content, 1.0 - 7.5%	200-5,000		343-892
Landfill/open dump fires	23-46		120-170

Appendix A: DIOXIN INVENTORIES IN LATIN AMERICA

Emission factors, in conjunction with activity levels, determine the estimated releases from each source category and, consequently, the priority – the relative importance – given to each source category in the National Action Plan that each Party must prepare within two years of the date of entry into force of the Stockholm Convention for that Party.[77] To illustrate the impacts of emission factors on estimates of dioxin releases and prioritization of sources, dioxin inventories for Argentina, Cuba and Mexico that were prepared using the Toolkit's emission factors are compared to those in which the emission factors presented in Table A.1 were used.

Table A.1: General, Single-Value Emission Factors [k]

	Emission factor for releases to air	**Emission factor for releases to land**	**Emission factor for releases to residues**
	ng TEQ/kg		
Forest fires, grassland and moor fires	0.5 [18]	0.05 [25]	
Agricultural residues, open burning	0.8 [17,18]	0.05 [25]	
Domestic waste, open burning	17 [48]		0.3 [48]

A.1 Argentina

Argentina prepared a dioxin inventory in 2004.[78] This inventory, which presents release estimates for the year 2001, is based entirely on the list of sources and emission factors presented in the draft Dioxin Toolkit of 2001.[4]

According to the 2001 inventory, the ten largest contributors to Argentina's total dioxin release of 2,111 g TEQ/year are the sources listed in the second column of Table A.2 below. As also shown in this table, with the emission factors given in Table A.1 for forest fires, grassland and moor fires, open burning of agricultural residues, and open burning of domestic waste, Argentina's total dioxin release is 489 g TEQ/year and the top ten dioxin sources are dramatically re-ordered..

Dioxin releases, by source category and receiving medium (air, water, land, products, or residues), as reported by Argentina using the Toolkit's emission factors, are shown in Figure A.1. Similar data are presented in Figures A.2 with the exception that dioxin releases from forest fires, grassland and moor fires, open burning of agricultural residues, and open burning of domestic waste were calculated using the emission factors given in Table A.1.

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[k] A range of values for each emission factor is greatly preferred. However, these values are presented in order to follow the model established by the UNEP Dioxin Toolkit and to facilitate comparisons with inventories that use the Toolkit's single-value emission factors.

Table A.2: Argentina – Top ten dioxin sources and estimated releases, based on Toolkit emission factors only and on most appropriate emission factors for selected sources -- forest fires, grassland and moor fires, open burning of agricultural residues and open burning of domestic waste

	Toolkit emission factors				Appropriate emission factors for selected sources	
Rank		grams TEQ/year		Rank		grams TEQ/year
1	Uncontrolled domestic waste burning	1077.4		1	Medical/hospital waste incineration	92.5
2	Grassland and moor fires	266.3		2	Pulp and paper mills	79.2
3	Forest fires	206.1		3	Iron and steel plants	46.2
4	Agricultural residue burning (in field),	124.2		4	Coal fired stoves	42.0
5	Medical/hospital waste incineration	92.6		5	Hazardous waste incineration	33.7
6	Pulp and paper mills	79.2		6	Copper production	28.5
7	Iron and steel plants	46.2		7	Other biomass fired power boilers	24.6
8	Coal fired stoves	42.0		8	Sewage/sewage treatment – no sludge removal	22.7
9	Hazardous waste incineration	33.7		9	Uncontrolled domestic waste burning	20.7
10	Copper production	28.5		10	Grassland and moor fires	16.3
	Others	115.1			Others	83
	Total	2111			Total	489

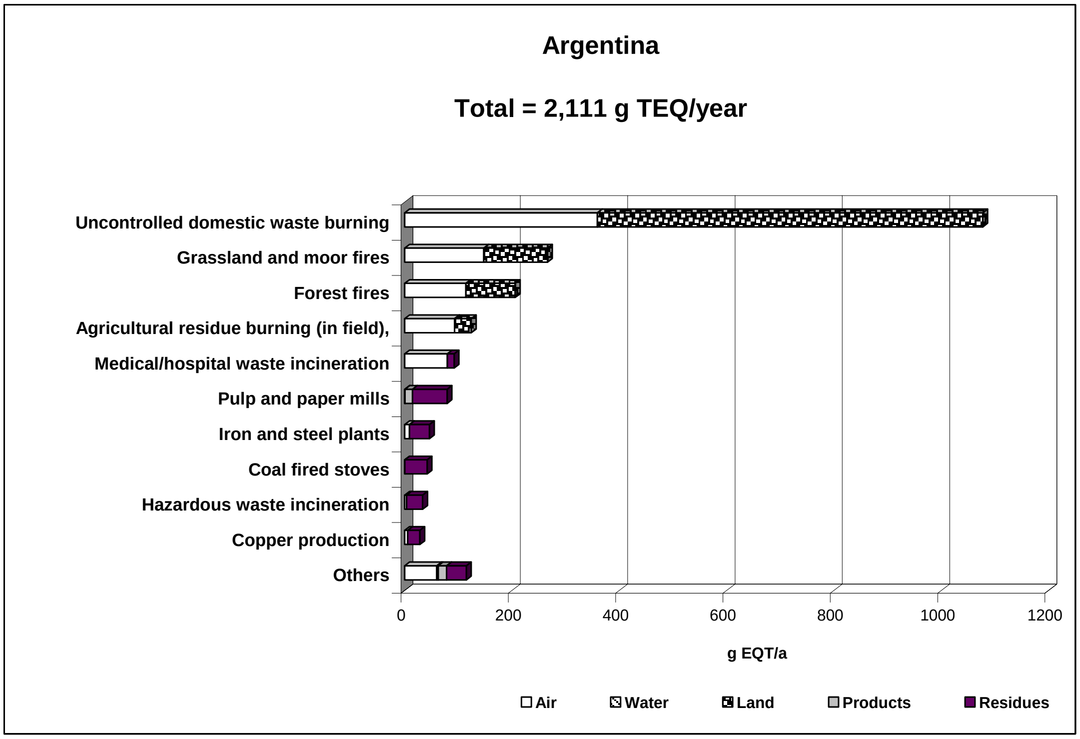

Figure A.1: Argentina -- Ten largest dioxin source categories, based on emission factors from UNEP Dioxin Toolkit (2001)

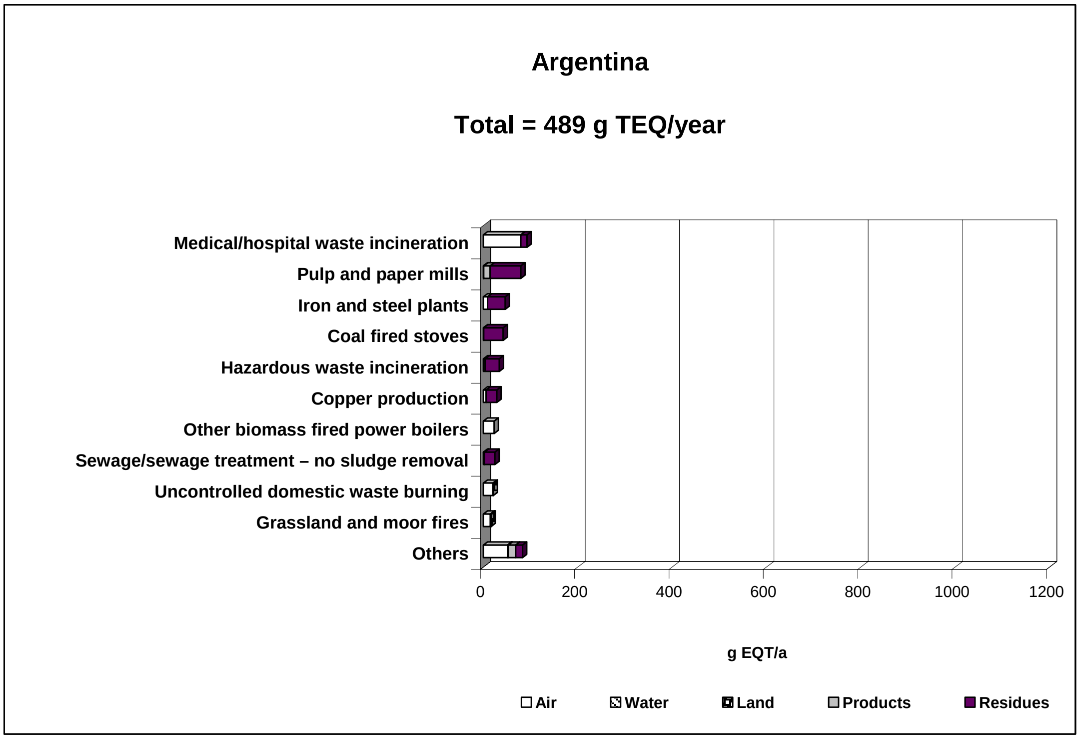

Figure A.2: Argentina -- Ten largest dioxin source categories, based on emission factors for selected sources (forest fires, grassland and moor fires, open burning of agricultural residues, uncontrolled burning of domestic waste) shown in Table A.1

A.2 Cuba

Cuba prepared a dioxin inventory in 2003. [79] This inventory, which presents release estimates for the year 2001, is based entirely on the list of sources and emission factors presented in the draft Dioxin Toolkit of 2001. [4]

According to the 2001 inventory, the ten largest contributors to Cuba's total dioxin release of 319 g TEQ/year are the sources listed in the second column of Table A.3. The data in this table also show that, with the use of emission factors given in Table A.1 for forest fires, grassland and moor fires, open burning of agricultural residues, and open burning of domestic waste, Cuba's total dioxin release is 151 g TEQ/year and the top ten dioxin sources are dramatically re-ordered.

Dioxin releases, by source category and receiving medium (air, water, land, products, or residues), based on the Toolkit's emission factors are presented in Figure A.5, while Figure A.6 shows the percent contribution of each source category. Similar data are presented in Figures A.7 and A.8 except that dioxin releases from forest fires, grassland and moor fires, open burning of agricultural residues, and open burning of domestic waste were calculated by using the emission factors given in Table A.1.

Table A.3: Cuba – Top ten dioxin sources and estimated releases, based on Toolkit emission factors only and on most appropriate emission factors for selected sources -- forest fires, grassland and moor fires, open burning of agricultural residues and open burning of domestic waste

	Toolkit Emission Factors			Appropriate emission factors for selected sources	
Rank		grams TEQ/year	Rank		grams TEQ/year
1	Uncontrolled domestic waste burning	148.4	1	Biomass Power Plants	55.2
2	Biomass Power Plants	55.2	2	Medical/hospital waste incineration	31.7
3	Medical/hospital waste incineration	31.7	3	Animal carcasses burning	23.5
4	Animal carcasses burning	23.5	4	Iron and steel production	8.5
5	Agricultural residue burning (in field),	21.3	5	Thermal Non-ferrous metal production	7.1
6	Iron and steel production	8.5	6	Composting	5.1
7	Thermal Non-ferrous metal production	7.1	7	Copper production	4.2
8	Composting	5.1	8	Cement kilns	3.7
9	Copper production	4.2	9	Uncontrolled domestic waste burning	2.9
10	Cement kilns	3.7	10	Aluminum production	1.8
	Others	9.9		Others	7.1
	Total	319		Total	151

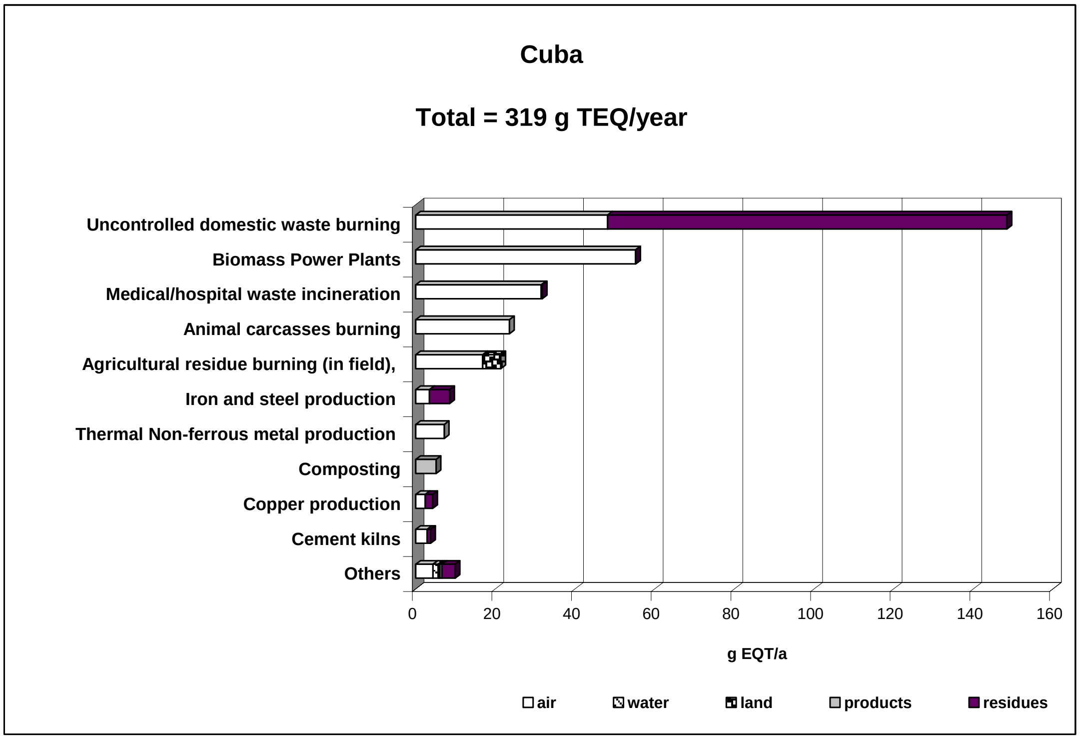

Figure A.3: Cuba -- Ten largest dioxin source categories, based on emission factors from UNEP Dioxin Toolkit (2001)

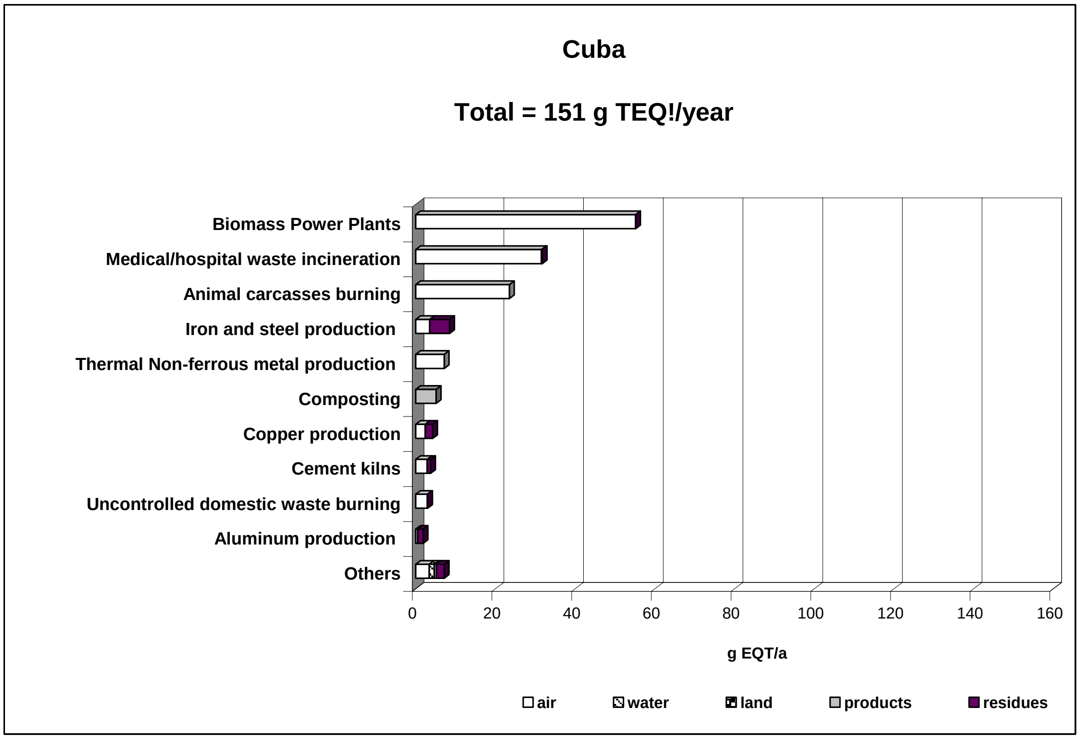

Figure A.4: Cuba -- Ten largest dioxin source categories, based on revised emission factors for selected sources (forest fires, grassland and moor fires, open burning of agricultural residues, uncontrolled burning of domestic waste), as shown in Table A.1

A.3 México

México has prepared a series of dioxin inventories in which dioxin releases were estimated for the year 2000:

- In the first inventory, which was prepared by García et al. (2001), [80] dioxin releases for each source category were calculated using emission factors that were the same as those used by the U.S. Environmental Protection Agency for the 1998 U.S. dioxin inventory; [81]
- Gutiérrez et al. (2002) prepared a revised version of the first inventory in 2002, again based on the same emission factors as those used by the U.S;[82]
- Alvarado and Gutiérrez (2003) prepared a third report in which dioxin releases were estimated using the Toolkit emission factors and compared with release estimates that were said to be taken from Gutiérrez et al. (2002); [83] and
- At an international conference in 1005, Alvarado et al. (2005) presented a paper said to describe the comparison of release estimates based on Toolkit emission factors and those based on U.S. emission factors as reported by Alvarado and Gutiérrez (2003). [84]

For dioxin releases for forest fires, these reports are inconsistent with regard to estimates based on both U.S. emission factors and Toolkit emission factors. As presented in Table A.4 below, the report by Alvarado and Gutiérrez (2003) presents two different release estimates – 1.85 g TEQ/year and 57.91 g TEQ/year – that are attributed to the U.S. emission factor and two different estimates for total releases – 49.23 g TEQ/year and 260.59 g TEQ/year – that are attributed to the Toolkit emission factors. [83]

Table A.4: Mexico -- Estimated dioxin releases from forest fires, as presented in various reports

	Release, based on U.S. emission factor, g TEQ/yr	Release, based on Toolkit emission factors, g TEQ/yr		
		Air	Land	Total
García et al. (2001) [80]	1.85	--	--	--
Gutiérrez et al. (2002) [82]	1.85	--	--	--
Alvarado and Gutiérrez (2003) [83]	57.91 [l]	27.35 [m]	21.88 [m]	49.23 [n]
	1.85 [o]	nv	nv	260.59 [p]
Alvarado et al. (2005) [84]	1.85	nv	nv	49.2

nv = no value reported

No absolute value for the activity level – the tons of biomass burned per year – for forest fires was found in any of the reports. However, this value can be determined by back-calculating from the total releases and their associated emission factors:

- With the U.S. air emission factor of 2 ng TEQ/kg and a total release of 1.85 g TEQ/year, the mass of materials burned can be calculated to be 925,000 tons/year. Applying the Toolkit's emission factors -- 5 ng TEQ/kg (air) and 4 ng TEQ/kg (land) -- to this value results in an air release of 4.6 g TEQ/year and a release to land of 3.7 g TEQ/year for a total dioxin release

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[l] Tabla A, page iii; Tabla 7.2, page 65

[m] Tabla 1.1, page 6.

[n] Gráfica 1.1, page 7.

[o] Tabla 1.1, page 6 ; Gráfica 1.1, page 7.

[p] Tabla A, page iii ; Tabla 7.1, page 64..

of 8.3 g TEQ/year. As shown in Table 4, no similar value for total dioxin release from forest fires appears in any of those reported in the four reports.

- With the U.S. air emission factor of 2 ng TEQ/kg and a total release of 57.91 g TEQ/year, the mass of materials burned can be calculated to be 28,955,000 tons/year. Applying the Toolkit's emission factors -- 5 ng TEQ/kg (air) and 4 ng TEQ/kg (land) -- to this value results in an air release of 144.8 g TEQ/year and a release to land of 115.8 g TEQ/year for a total dioxin release of 260.6 g TEQ/year. This total release value is identical to one of the two total release values reported by Alvarado and Gutiérrez (2003). [83]

- The larger value – 28,955,000 tons/year – for the amount of biomass burned during forest fires in Mexico is commensurate with the values reported by other countries. For example, Argentina reported 22,901,192 tons/year of biomass burned in forest fires. [78]

It is apparent that some of the values for estimated dioxin releases from forest fires that are given in the four reports are the results of typographical or other errors. Further, as described above, the amount of biomass burned during forest fires in Mexico is assumed in this report to be 28,955,000 tons/year. [q] Based on this assumption, total dioxin releases due to forest fires are estimated to be 57.91 g TEQ/year, using the U.S. air emission factor, and 260.6 g TEQ/year, using the Toolkit emission factors.

The reports are also inconsistent with respect to dioxin releases from burning agricultural residues. For example, both Alvarado and Gutiérrez (2003) and Alvarado et al. (2005) present an estimate of about 222 g TEQ/year based on the U.S. emission factor. However, for the release based on the Toolkit emission factors, Alvarado and Gutiérrez (2003) give an estimate of 442.98 g TEQ/year, while an estimate of 1,163 g TEQ/year is given by Alvarado et al. (2005). [83, 84] Based on the reported activity level for burning agricultural residues of 110,750,000 tons/year, 1,163 g TEQ/year is the correct value for dioxin release from this source.

Taking into account the above corrections and assumptions, México's total dioxin release is 3,864 g TEQ/year, based on Toolkit emission factors only, and the top ten sources are those listed in the second column of Table A.5. The data in this table also show that, with the use of emission factors given in Table A.1 for forest fires, grassland and moor fires, open burning of agricultural residues, and open burning of domestic waste, México's total dioxin release is 1,294 g TEQ/year and the top ten dioxin sources are dramatically re-ordered.

Dioxin releases, by source category and receiving medium (air, water, land, products, or residues), based on the Toolkit's emission factors are presented in Figure A.5. Similar data are presented in Figures A.6 except that dioxin releases from forest fires, grassland and moor fires, open burning of agricultural residues, and open burning of domestic waste were calculated by using the emission factors given in Table A.1.

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[q] Correction and/or confirmation of this value will be welcomed.

Table A.5: México -- Top ten dioxin sources and estimated releases, based on Toolkit emission factors only and on most appropriate emission factors for selected sources -- forest fires, grassland and moor fires, open burning of agricultural residues, open burning of domestic waste, and open dump fires

	Toolkit Emission Factors				Appropriate emission factors for selected sources	
Rank		grams TEQ/year		Rank		grams TEQ/year
1	Agricultural residue burning	1162.88		1	Industrial waste incineration	724.98
2	Open dump fires	824.82		2	Open dump fires	222.5
3	Industrial waste incineration	724.98		3	Metals production	180.97
4	Uncontrolled domestic waste burning	666.9		4	Agricultural residue burning	94.1
5	Forest fires	260.58		5	Medical/hospital waste incineration	33.61
6	Metals production	180.97		6	Forest fires	15.95
7	Medical/hospital waste incineration	33.61		7	Uncontrolled domestic waste burning	12.8
8	Cement Kilns	4.18		8	Cement Kilns	4.18
9	VCM/PVC production	2.67		9	VCM/PVC production	2.67
10	Pulp and paper mills	1.34		10	Pulp and paper mills	1.34
	Others	1.148			Others	1.148
	Total	3864			Total	1294

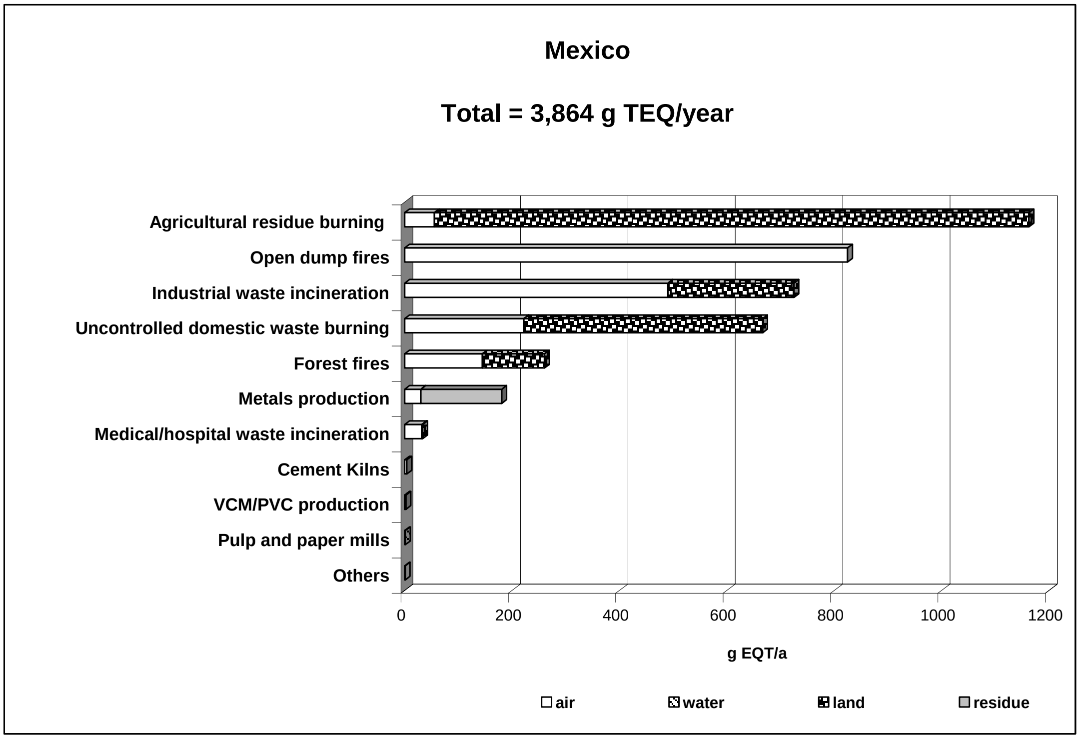

Figure A.5: Mexico -- Ten largest dioxin source categories, based on emission factors from UNEP Dioxin Toolkit

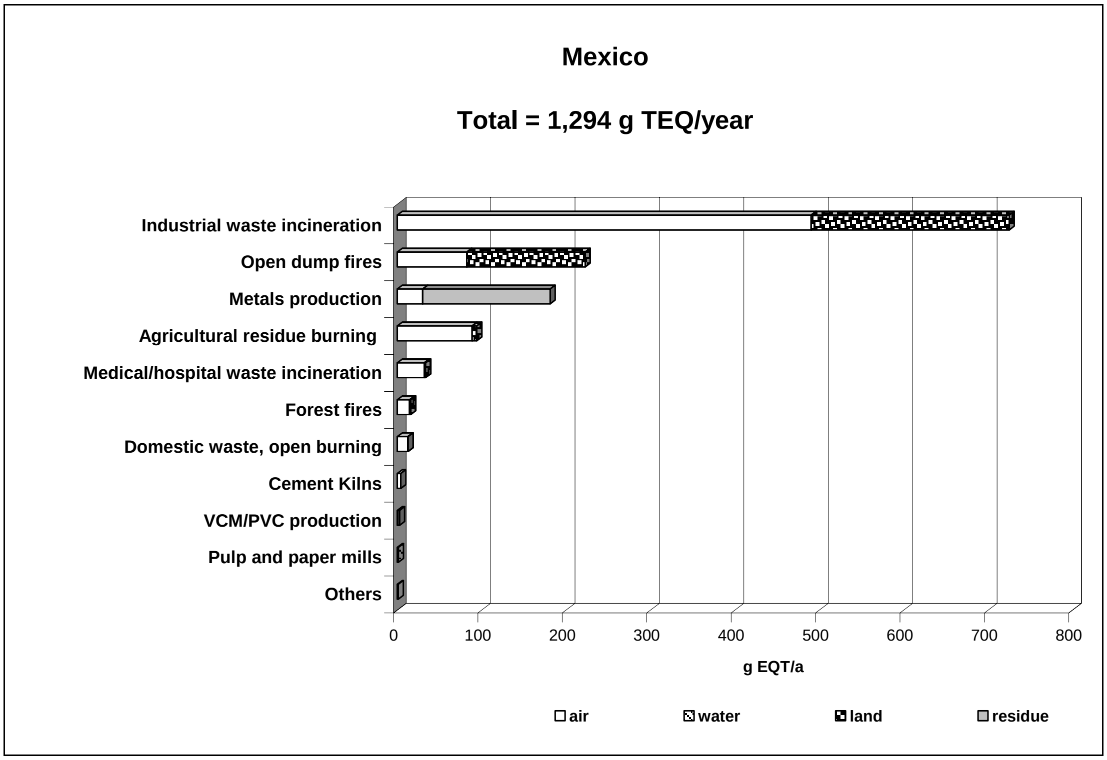

Figure A.6: Mexico -- Ten largest dioxin source categories, based on revised emission factors for selected sources (forest fires, grassland and moor fires, open burning of agricultural residues, uncontrolled burning of domestic waste, and open dump fires)

As mentioned above, Alvarado and Gutiérrez (2003) and Alvarado et al. (2005) also compared dioxin releases from the largest source categories using U.S. emission factors and releases based on the Toolkit emission factors.[83, 84] However, neither comparison is useful. For the sources under consideration, U.S. emission factors are limited to air releases so that releases to other media, such as land and residues, are not included, while the Toolkit presents emission factors for releases to these other media as well. In addition, even though the comparison by Alvarado et al. (2005) is said to be taken from the earlier comparison by Alvarado and Gutiérrez (2003), there are obvious, unexplained differences in the release estimates attributed to forest fires and burning of agricultural residues.

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