GUIDELINES ON BEST AVAILABLE TECHNIQUES AND PROVISIONAL GUIDANCE ON BEST ENVIRONMENTAL PRACTICES

relevant to Article 5 and Annex C of the Stockholm Convention on Persistent Organic Pollutants

Fossil fuel-fired utility and industrial boilers

UNEP

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May 2007, Geneva, Switzerland

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VI.D Fossil fuel-fired utility and industrial boilers

Summary

Utility and industrial boilers are facilities designed to burn fuel to heat water or to produce steam for use in electricity generation or in industrial processes. The volumetric concentrations of chemicals listed in Annex C of the Stockholm Convention in the emissions from fossil fuel-fired boilers are generally very low. However, the total mass emissions from the boiler sector may be significant because of the scale of fossil fuel combustion, in terms of both tonnage and distribution, for electricity generation and heat or steam production.

Measures that can be taken to decrease the formation and release of chemicals listed in Annex C include: maintenance of efficient combustion conditions within the boiler and ensuring sufficient time is available to allow complete combustion to occur; undertaking measures to ensure fuel is not contaminated with PCB, HCB or chlorine, and is low in other components known to act as catalysts in the formation of PCDD and PCDF; use of appropriate gas-cleaning methods to lower emissions that may contain entrained pollutants; and appropriate strategies for disposal, storage or ongoing use of collected ash.

PCDD/PCDF air emission levels associated with best available techniques can be significantly lower than 0.1 ng I-TEQ/Nm^3 (oxygen content: 6% for solid fuels; 3% for liquid fuels).

1. Introduction

1.1 Overview of boilers

Boilers are facilities designed to burn fuel to heat water or to produce steam. The majority of boilers use fossil fuels to provide the energy source, although boilers can also be designed to burn biomass and wastes. The steam produced from the boiler can be used for electricity production or used in industrial processes; likewise hot water can be used in industrial processing, or for domestic and industrial heating. There are significant differences between utility and industrial boilers, with the major differences occurring in three principal areas:

- Size of the boilers;
- Applications for the steam and hot water produced by the boilers;
- Design of the boilers.

1.1.1 Size of boilers

Utility boilers are very large in comparison to modern industrial boilers (sometimes known as industrial/commercial/institutional boilers). A typical large utility boiler produces in the order of 1,600 tons of steam per hour compared to about 45 tons of

steam for the average industrial boiler, although industrial boilers may range from one-tenth to ten times this size (CIBO 2002).[1]

1.1.2 Applications for output steam

Utility boilers are designed to generate steam at a constant rate to power turbines for electricity production. Because of this constant demand for steam they generally operate continuously at a steady state, though changes in energy market structures may see some utilities varying operating conditions to address fluctuations in daily national energy demands.

By contrast, industrial boilers have markedly different purposes in different industrial applications and the demands can vary depending on the industrial activities and processes operating at any given time and their demand for steam; compare, for example, the production and use of both hot water and steam for food processing with the demand cycle in a large hospital boiler. These widely fluctuating steam demands mean that the industrial boiler does not generally operate steadily at maximum capacity, although the design will be optimized to the plant and its operation. In general, industrial boilers will have much lower annual operating loads or capacity factors than typical utility boilers.

1.1.3 Boiler design

Utility boilers are usually large units combusting primarily pulverized coal, fuel oil or natural gas at high pressure and temperature. Individual utility boiler types tend to have relatively similar design and fuel combustion technologies. Industrial boilers, however, can incorporate a wide range of combustion systems, although they are usually designed to specific fuel types. Utility plant facilities are designed around the boilers and turbine(s) and their size allows for significant economies of scale in the control of emissions. However, the design of industrial boilers can be constrained by the necessity for flexibility of steam output and plant space limitations. This may lead to more difficulty in applying effective emission controls to these industrial boiler applications.

1.2 Boiler types

1.2.1 Utility boilers

Utility boilers are usually designated by the combustion furnace configuration:

Tangentially fired: Commonly used for pulverized coal combustion but may be used for oil or gas; single flame zone with air-fuel mixture projected from the four corners of the furnace tangential to furnace centre line;

- Wall fired: Multiple burners located on a single wall or on opposing furnace walls can burn pulverized coal, oil or natural gas;
- Cyclone fired: Typically crushed coal combustion, where the air-fuel mixture is burnt in horizontal cylinders;
- Stoker fired: Older plants burning all solid fuel types; spreader stokers feed solid fuel onto a combustion grate and remove ash residue;

- Fluidized bed combustion: Lower furnace combustion temperature, efficient combustion promoted by turbulent mixing in the combustion zone, crushed coal feed with the potential for sorbent additions to remove pollutants, particularly sulphur dioxide;
- Pressurized fluid bed combustion: Similar to fluidized bed combustion, but at pressures greater than atmospheric, and with higher efficiency.

1.2.2 Industrial/commercial/institutional boilers

Industrial/commercial/institutional boilers are normally identified by the methods of heat transfer and combustion system utilized. A detailed discussion of the various boiler types can be found in Oland 2002. In summary, the heat transfer systems are:

- Water tube boilers: Heat transfer tubes containing water are directly contacted by hot combustion gases. Commonly used in coal-fired installations but can accommodate almost any combustible fuel including oil, gas, biomass, municipal solid waste and tyre-derived fuel;
- Fire tube boilers: Water surrounds tubes through which hot combustion gases are circulated. The application is more common for pulverized coal, gas and oil-fired boilers, but various types can also burn biomass and other fuels. Generally used for lower-pressure applications;
- Cast-iron boilers: Cast sections of the boiler contain passages for both water and combustion gas. Used for low-pressure steam and hot water production, generally oil or gas fired with a smaller number of coal-fired units.

And the combustion systems are mainly:

- Stokers: There are a variety of different stoker types and functions. Underfeed stokers supply both fuel and combustion air from below the grate, discharging ash to the side or rear. Overfeed stokers, which may be mass feed or the more popular spreader stoker, supply the combustion air from below the grate, with the fuel for combustion being distributed above the grate. Spreader stokers with a stationary grate are used extensively in the sugar industry to combust bagasse;
- Burners: This diverse group of devices manages the delivery of air-fuel mixtures into the furnace under conditions of velocity, turbulence and concentration appropriate to maintain both ignition and combustion.

2. Generation of PCDD/PCDF, PCB and HCB from combustion

In a properly operated combustion system, volatiles should be subjected to sufficient time at high temperature, with adequate oxygen and mixing, to enable uniform and complete combustion. When those conditions are not present the potentially toxic airborne emissions polychlorinated dibenzo-*p*-dioxins (PCDD), polychlorinated dibenzofurans (PCDF), polychlorinated biphenyls (PCB) and hexachlorobenzene (HCB) can be produced in or survive the combustion process (Van Remmen 1998; UNEP 2005).

In large, well-controlled fossil fuel-fired power plants, the formation of PCDD/PCDF (and other persistent organic pollutants) is low since the combustion efficiency is usually high, the process is stable and the fuels used are generally homogeneous. However, significant mass emissions are still possible as large volumes of flue gases are emitted with small concentrations of PCDD/PCDF (UNEP 2005). In smaller less well controlled systems there exists the potential for emissions of persistent organic pollutants at greater concentrations but at lower overall throughputs, therefore resulting in lower mass emission of such pollutants.

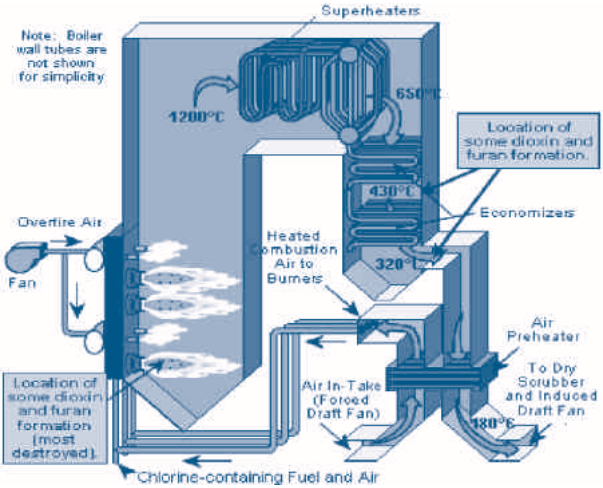
2.1 PCDD and PCDF

2.1.1 Generation of PCDD/PCDF

Fossil fuel combustion in utility or industrial boilers is known to generate much less PCDD/PCDF than combustion of waste-derived fuels (Sloss and Smith 1993; Sloss 2001; Dyke 2004). Griffin, in 1986, established a hypothesis to explain the formation of PCDD/PCDF as a result of the sulphur-to-chlorine ratio in the fuel feedstock (Griffin 1986). The hypothesis states that in coal there is a sulphur-to-chlorine ratio of 5:1, which is much greater than that found in municipal solid waste. This surplus of sulphur over chlorine in fossil fuels, such as coal, crude oil and gas, enables the capture of the molecular chlorine, thus preventing the formation of chlorinated aromatics that arise in the combustion waste-derived fuels, where chlorine dominates over sulphur.

PCDD/PCDF arise by a variety of mechanisms. Figure 1 shows a schematic representation of possible locations for PCDD/PCDF formation in a boiler. Further details on formation of PCDD/PCDF appear in section III.C (i) of the present guidelines.

Figure 1. Location of possible PCDD and PCDF formation in a boiler



Source: Modified from Richards 2004.

2.1.2 PCDD/PCDF control mechanisms

Combustion conditions, fuel quality and plant design and operating conditions can have a major influence on PCDD/PCDF formation. It has been shown (Williams 1994; Eduljee and Cains 1996) that combustion conditions can be improved to reduce PCDD emissions. Lemieux (1998) summarizes work at the United States Environmental Protection Agency that shows, in decreasing order of importance, the parameters that can be controlled to reduce PCDD/PCDF emissions:

1. Combustion quality as indicated by:
   - Carbon monoxide (CO), total hydrocarbons, soot formation;
   - Particle entrainment and burnout;
2. Air pollution control temperatures;
3. Fuel/waste parameters:
   - Sulphur;
   - Metals;
   - Chlorine.

These can be achieved by the following conditions (Lemieux 1998):

- Uniform high combustor temperature;
- Good mixing with sufficient air;
- Minimize entrained, unburnt particulate matter;

- Feed rate uniformity;
- Active monitoring and control of CO and total hydrocarbons.

Finally, a number of operating parameters for air pollution control devices have been identified to result in lower PCDD/PCDF emissions. These are:

- Low temperature at the particulate control device inlet;
- Minimization of gas or particle residence time in the 200°–400°C temperature window.

As mentioned previously, the presence of sulphur has also been shown to inhibit PCDD formation, based on the generally low emissions from coal-fired power plants, and results obtained from the co-firing of high-sulphur coal with refuse-derived fuel (Tsai et al. 2002). Thus there may be benefits in maintaining a high sulphur-low chlorine ratio (Luthe, Karidio and Uloth 1997), although it should be recognized that the use of high-sulphur fuels may result in the development of a different set of air pollution problems.

2.2 PCB and HCB

PCB emissions may arise from the use of recovered oils and other waste-derived fuels. Coal combustion is the third-largest global source of HCB emissions (Bailey 2001). Further details on the formation of these compounds appear in section III.C (i) of the present guidelines. Similar emission control strategies to those used for minimizing PCDD/PCDF emissions can be used for the control of PCB and HCB emissions.

3. Effect of fuel types on generation of emissions

The fossil fuels – coal, oil and gas – are used, either individually or in combination with energy-containing fuels from other processes, for steam generation in boilers. The type of fuel used depends on fuel availability and process economics.

3.1 Light fuel oil and natural gas

Light fuel oil and natural gas are always fired in specially designed burners and are generally unlikely to generate large amounts of PCDD/PCDF, as both are very high-calorific, clean-burning fuels leaving little ash. Increased gas use for power generation (as a replacement fuel for coal and oil) will result in reductions of PCDD/PCDF from the generation sector (UNECE 1998).

3.2 Heavy fuel oil

Heavy fuel oil is combusted for both steam generation and power generation purposes and is usually burnt in specially designed burners incorporated in the boiler walls. Heavy fuel oil that is free from contaminants will generally result in low levels of organic emissions.

3.3 Coal

Efficient coal combustion in large coal-fired power plants results in very low levels of emissions (Rentz, Gütling and Karl 2002). Coal use in less-efficient sectors could be a significant source of local emissions (Sloss 2001). UNECE 1998 recommends the improvement of energy efficiency and energy conservation for utility and industrial boilers over 50 MW as an emissions reduction strategy due to lowered fuel requirements. However, it is acknowledged that while techniques for the reduction of particles, sulphur oxides (SO_x) and nitrogen oxides (NO_x) may result in the reduction or removal of PCDD/PCDF (and presumably PCB and HCB), the removal efficiencies will be variable (see also section III.C (iii) on co-benefits). Chlorine removal from fossil fuel feeds is not seen as a cost-effective measure for PCDD/PCDF reduction (UNECE 1998).

3.4 Lignite

Lignite-fired power plants are typically operated close to the mining region. Due to the significantly lower calorific value of lignite compared to coal it is mainly transported via belt conveyors from the storage area of the mine to the power station. Pulverized lignite-fired combustion and fluidized bed combustion are appropriate techniques for power generation from lignite. Due to lower combustion temperatures, pulverized lignite-fired boilers can achieve current NO_x emission standards by primary measures. Therefore, they typically do not use selective catalytic reduction.

PCDD/PCDF emissions from lignite-fired power plants have been reported in a range of 0.0002 to 0.04 ng I-TEQ/Nm^3 (Detzel et al. 1998).[2]

3.5 Co-firing with other fuel types

Most electricity-generating plants use a single fuel, but it is possible to modify the boiler and the fuel processing equipment to blend other materials, such as waste, into the fuel mix. This process of co-firing means that more than one fuel type can be used simultaneously.

Boilers, however, are often limited in their capability to use waste or waste-derived fuels due to a lack of hydrogen chloride emission control, and sometimes by combustion condition limitations and possible boiler corrosion problems. The potential for emission of persistent organic pollutants may be increased by co-firing if boiler efficiency is not maintained by appropriate system redesign or control.

Wastes (also known as waste-derived fuels) are materials that are rich in energy, such as used oil, tyres, waste wood and spent solvents, which can be used to replace fossil fuels as a source of thermal energy. However, in many cases waste fractions with a low calorific value (such as dewatered sewage sludge) are also co-incinerated for disposal. Potential contamination of waste by undesirable materials or pollutants is an issue associated with this fuel source. In particular, the presence of PCB, HCB and chlorine in the waste should either be specifically precluded or limited. For further guidance on the issues and implications of using waste types refer to the guidance presented in the sections on waste incinerators, cement kilns firing hazardous waste, firing installations for wood and other biomass fuels, and waste oil refineries (sections V.A, V.B, VI.E and VI.M of the present guidelines).

Fuel quality management and good combustion conditions, in combination with an effective collection device, appear to offer the most successful control strategies for minimization of persistent organic pollutants when waste material is included amongst the fuel loading. For the most effective operation, waste materials should be specifically excluded from the process during start-up, shutdown or in stationary operating conditions, when combustion conditions are less likely to be both stable and controlled.

Co-incineration of waste should be done in such a way that disposal options of solid residues (e.g. fly ash, coarse ash, flue gas treatment residues) are not negatively affected (see section V.A (waste incinerators) of the present guidelines).

If an emission value of 0.1 ng/Nm^3 is not met, secondary measures are available and should be installed.

4. Estimation of emissions of persistent organic pollutants from boilers

Measurement of the low levels of PCDD, PCDF, PCB and HCB from the combustion of fossil fuels in boilers is technically challenging and costly compared with the measurement of criteria pollutants such as sulphur dioxide, oxides of nitrogen and particulates. Although the direct measurement of persistent organic pollutants from individual facilities is encouraged to improve the knowledge base of emissions of these toxic components, it is acknowledged that in some circumstances this may not be possible except for those operating large and technically advanced facilities.

In an efficient combustion process the levels of pollutants may be up to several orders of magnitude below prevailing standards (Brain et al., cited in Sloss 2001). As a result, although PCDD, PCDF, PCB and HCB may possibly be present, they may be below the detection limits of currently available analytical methods.

An alternative to direct measurement is the calculation of an imputed emission output given some knowledge of fuel type, throughput and process conditions. PCDD/PCDF emission factors (I-TEQ) for a number of boiler processes are given in Table 1, with additional information on emission of particular congeners included as annex I to the present section (UNEP 2005).

Table 1. Emission factors for heat and power generation plants in industry fuelled with fossil fuels

Classification	Emission Factors - mg TEQ/TJ of Fossil Fuel Burned		
	Air	Water	Residue
1 Fossil fuel/waste co-fired power boilers	35	n.d.	n.d.
2 Coal fired power boilers	10	n.d.	14
3 Heavy fuel fired power boilers	2.5	n.d.	n.d.
4 Shale oil fired power plants	1.5	n.d.	*
5 Light fuel oil/natural gas fired power boilers	0.5	n.d.	n.d.

* Releases with residues can be calculated on a mass basis

Source: UNEP 2005

n.d. Not determined.

a. These default emission factors are based on the assumption that the fuels burnt lead to PCDD/PCDF releases associated with the disposal of fly ash. Emissions through bottom ash are negligible. The removal efficiency of particulate matter also increases with the quality of the air pollution control system employed at the plant (UNEP 2003).

b. Energy throughput basis: µg TEQ/TJ of fuel consumed.

Information on emissions is more readily available for PCDD/PCDF than for PCB and HCB. Where waste-derived fuels comprise a significant proportion of the fuel feed it may be appropriate to source emission factors from the waste incineration sector (UNEP 2003). For PCB and HCB emissions few or no reliable data are available for the boiler combustion sector.

5. Best environmental practices

The best environmental practices described in this section constitute general guidance applicable to any kind of boiler, regardless of its size or type:

- Identify key process parameters, either from site-specific investigations or research undertaken on similar facilities elsewhere;
- Introduce measures that enable control of key process parameters;
- Introduce monitoring and reporting protocols for key process parameters;
- Introduce and follow planning cycles, implement appropriate inspection and maintenance cycles;
- Introduce an environmental management system that clearly defines responsibilities at all levels;

- Ensure adequate resources are available to implement and continue best environmental practices;
- Introduce process improvements to reduce technical bottlenecks and delays;
- Ensure all staff are appropriately trained in the application of the best environmental practices relevant to their duties;
- Define a fuel specification for key fuel parameters and introduce a monitoring and reporting protocol;
- Ensure the environmentally sound management of fly ash, coarse ash and flue gas treatment residues;
- Ensure that, when co-firing biomass or waste, they should not be added until the boiler furnace combustion conditions are stable and it has reached its operating temperature.

6. Best available techniques

In order to reduce the emission of persistent organic pollutants from fossil fuel-fired utility and industrial boilers, the pathways for generation and release of such pollutants must be minimized in the design and operation of the process. This will be effectively achieved by addressing:

- Fuel quality;
- Combustion conditions;
- Installation of the most appropriate air pollution control devices.

6.1 Primary measures

6.1.1 Fuel specification and monitoring

While the low levels of precursors necessary to promote the formation of chemicals listed in Annex C of the Stockholm Convention via gas formation above 500°C occur in most fuels, measures must be taken to reduce, to the extent possible, the unintentional introduction of contaminated fuels, which may promote the formation of persistent organic pollutants. This is especially valid when co-firing fossil fuels with other fuel types. Controls should be introduced (e.g. measurement of the chlorine content of fuel oil to prevent the introduction of PCB-contaminated waste oils) to ensure that the fuels used are within the required specifications.

6.1.2 Combustion conditions

To achieve the complete combustion of persistent organic pollutants contained in the fuel, special attention must be paid to the four cornerstones of high destruction efficiency: temperature, time, turbulence and excess oxygen (McKay 2002). This will also ensure the destruction of precursors and reduce soot formation and therefore provide

fewer possible sites for solid catalysis in the cooling gas effluent. Table 2 illustrates the influence of combustion conditions on emission of pollutants from waste-derived fuel. While the values in Table 2 are higher than might be expected from combustion using fossil fuels, the values illustrate the significant influence of combustion conditions (Environment Canada, cited in Dyke 2004).

Table 2. Trace organic concentrations (ng/Sm³ at 12% O_2)[a] for waste derived fuel combustion

Species	Good combustion	Poor combustion
PCDD (total)	70–230	200–600
PCDF (total)	220–600	700–1,300
Cl_{3-6} benzenes[b]	4,000–6,000	7,000–16,000

a. Sm^3 = standard cubic metre, dry gas volume measured at 15°C and 101.3 kPa (compare Nm^3, normal cubic metre, dry gas volume measured at 0°C and 101.3 kPa).

b. Includes all of the congeners of tri, tetra and penta as well as the fully substituted hexa.

It is generally accepted that a temperature in excess of 900°C (McKay 2002) and a gas residence time of 2 seconds are sufficient to achieve complete oxidation of PCDD, as long as the gas flow is sufficiently turbulent and excess O_2 is present. McKay (2002) suggests that a furnace temperature higher than 1,000°C should be maintained to ensure that all persistent organic pollutants are oxidized.

Other important factors are the excess air and turbulent conditions in the furnace. High degrees of turbulence will avoid the formation of cold pockets where oxidation temperatures will not be reached. High turbulence will also lead to uniform distribution of oxygen to ensure total combustion, avoiding substoichiometric zones, providing that air is in excess. To assess the efficiency of combustion, real-time monitoring of CO can be useful. Good combustion is accompanied by low CO emissions (i.e., 30–50 mg/Nm^3, 6% oxygen for pulverized coal; <100 mg/Nm^3 for fluidized bed combustion) (European Commission 2003). High CO levels indicate incomplete combustion and conditions under which persistent organic pollutants may survive or be created.

When solid fuel is used, in order to maximize mixing and combustion conditions, low-moisture pulverized fuels are to be preferred to crushed or lumpy fuels. Evaporation is an endothermic reaction and when moisture is introduced into the furnace combustion temperature decreases. Introducing pulverized fuel will allow, under good turbulent conditions, isothermal conditions throughout the entire furnace and optimum mixing with oxygen.

6.2 Secondary measures: Air pollution control devices

Air pollution control devices can be installed to further control and limit emissions, although in the case of fossil fuel-fired utilities and industrial boilers, these devices are additional or secondary measures. More details on air pollution control devices are provided in section III.C (iv) of the present guidelines.

6.3 Other considerations

It should be noted that the formation of PCDD, PCDF, PCB and HCB is complex and the removal of particles in the flue gases does not mean persistent organic pollutants will not be emitted. These cleaning techniques, while still of great importance to our environment, should not be considered as the only solution. As mentioned earlier, fuel quality and combustion control are most important steps in minimizing emissions of persistent organic pollutants.

The capture of particles from the flue gases may produce an amount of contaminated dust waste, which should be handled with care as a possible product containing persistent organic pollutants (UNECE 1998). Generally, combustion products such as fly ash and bottom ash from pulverized coal combustion contain very low residual levels of persistent organic pollutants, with PCDD less than 1 pg I-TEQ/g (Meij and te Winkel 2001). Disposal methods are therefore likely to be dictated by prevention of release of other possible contaminants in the material rather than by any persistent organic pollutants that may be present. For residues containing higher levels of contamination, several techniques are recommended for reduction of persistent organic pollutants before disposal. These include catalytic treatment at low temperatures and with reduced oxygen concentrations, extraction of the heavy metals and combustion to destroy organic matter, vitrification and plasma technology (UNECE 1998).

A summary of measures constituting best environmental practices and best available techniques is presented in Table 3.

Table 3. Summary of recommended measures for fossil fuel-fired utilities and industrial boilers

Issue	Best environmental practices	Best available techniques	Environmental benefit
Fuel	Fuel sourcing Fuel monitoring Fuel specifications	Control fuel input to meet specifications by rejection, substitution, purification or blending	Minimization of persistent organic pollutants introduced into the combustion system
Combustion conditions	Design appropriate reactor for the specified fuel usage Monitor combustion conditions, particularly: • Temperature (>900°C) • Time (>1 second) • Turbulence (high) • Oxygen (in excess) Operate and maintain to achieve designed conditions Develop specific conditions and operating procedures for co-firing, particularly during furnace start-up and shutdown	Automated or computerized combustion control system to maintain ideal combustion conditions Maximized oxidation by maintaining ideal fuel/oxygen mix	Destruction of compounds of persistent organic pollutants present in the fuel Minimization of formation of persistent organic pollutants during combustion
Collection	Operation and maintenance of existing air pollution control devices	Assess potential for environmental improvement by installation of air pollution control device Install air pollution control device when environmental benefits can be demonstrated	Minimize persistent organic pollutant content of gases
Waste disposal	Collect solid and liquid wastes from the combustion process and air pollution control device Handle and store appropriately to minimize environmental release	Assess potential for waste volume reduction and recycling Safe disposal	Minimize and control the release to the environment

7. Performance levels associated with best available techniques

The available data suggest that for an effective boiler system using only coal, oil or gas as the fuel, achievable performance level for volumetric emissions of PCDD/PCDF from fossil fuel-fired utility and industrial boilers will usually be well below 0.1 ng I-TEQ/Nm^3. (Oxygen content 6% for solid fuels; 3% for liquid fuels).

Annex I. Emission factors[a] for PCDD/PCDF from controlled bituminous and sub-bituminous coal combustion (TEQ ng/kg[b])

Congener	Flue gas desulphurization spray dryer absorber and fabric filter[c]	Electrostatic precipitator or fabric filter[d]
2,3,7,8-TCDD	n.d.	0.0072
Total TCDD	0.197	0.046
Total PeCDD	0.353	0.022
Total HxCDD	1.50	0.014
Total HpCDD	5.00	0.042
Total OCDD	14.4	0.208
Total PCDD[e]	**21.4**	**0.333**
2,3,7,8-TCDF	n.d.	0.026
Total TCDF	1.25	0.202
Total PeCDF	2.42	0.177
Total HxCDF	6.35	0.096
Total HpCDF	22.0	0.038
Total OCDF	68.5	0.033
Total PCDF[e]	**101**	**0.545**
TOTAL PCDD/PCDF	**122**	**0.880**

n.d. Not determined.

a. EPA (1998) data converted from lb/ton coal combusted to ng/kg.

b. Emission factor should be applied to coal feed, as fired. Emissions are ng of pollutant per kg of coal combusted.

c. Factors apply to boilers equipped with both flue gas desulphurization spray dryer absorber and fabric filter. SCCs = pulverized coal-fired, dry bottom boilers, 1-01-002-02/22, 1-02-002-02/22, and 1-03-002-06/22.

d. Factors apply to boilers equipped with electrostatic precipitator or fabric filter. SCCs = pulverized coal-fired, dry bottom boilers, 1-01-002-02/22, 1-02-002-02/22, and 1-03-002-06/22; and cyclone boilers, 1-01-002-03/23, 1-02-002-03/23, and 1-03-002-03/23.

e. Total PCDD is the sum of total TCDD through total OCDD. Total PCDF is the sum of total TCDF through total OCDF.

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Notes

[1] For a rough estimation a conversion factor of 0.8–0.9 (MWh per ton of high pressure steam) can be used.

[2] 1 ng (nanogram) = 1×10^{-12} kilogram (1×10^{-9} gram); Nm^3 = normal cubic metre, dry gas volume measured at 0°C and 101.3 kPa. For information on toxicity measurement see section I.C, subsection 3 of the present guidelines.

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