Environment International 36 (2010) 131–137

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Review article

# Toxic emissions from crematories: A review

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ARTICLE INFO

*Article history:*
Received 16 July 2009
Accepted 17 September 2009
Available online 12 October 2009

*Keywords:*
Crematories
Toxic emissions
Dioxins and furans
Mercury
Health risks

ABSTRACT

In recent years, the cremation ratio of cadavers has increased dramatically in many countries. Crematories have been identified as sources of various environmental pollutants, being polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs), and mercury those raising most concern. In contrast to other incineration processes for which the number of studies on their toxic emissions is considerable, references related to PCDD/F and mercury emissions from crematories and their health risks are very limited. In this paper, the scientific information concerning these issues, using the databases PubMed, Scopus and Scirus, is reviewed. Results show that in comparison with PCDD/F emissions from other sources, those corresponding to crematories are significantly lower, while those of mercury should not be underrated.



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## 1. Introduction: incinerators, crematories and toxic emissions

Nowadays, there are more than 1000 crematories in Europe (United Kingdom: 250, France: 125, Spain: 132, Sweden: 68, etc) being the percentage of cremations approximately 37% (ICS, 2006). In 2006, the total number of cremations in Europe was more than 1,500,000 (ECN, 2008). In turn, the countries with the highest number of crematories are China and Japan, with 1549 and 1500, respectively (data from 2006) (ICS, 2006). The pollutants emitted by the combustion of organic matter with presence of other trace elements are: combustion gases ($NO_x$, CO, $SO_2$, PM….), heavy metals, and polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs), among other persistent organic pollutants. Heavy metals and PCDD/Fs, stand out because of their toxicity and capacity for bioaccumulation, which means potential risks for human health. Because of their toxicological properties, together with their persistence capacity, PCDD/Fs were listed by the Stockholm Convention on Persistent Organic Pollutants of 2001 as one of the "dirty dozen" pollutants whose levels should be significantly reduced. With regard to heavy metals, although most elements may be removed from crematory emissions through particulate control devices (EDI, 2006), as the concentrations of mercury may be considerable in human bodies due to the use of dental amalgam fillings, special attention should be paid to this toxic metal.

Environmental policies are becoming more and more stringent with respect to the emission limits of potentially toxic pollutants. However, monitoring surveys are important in order to ensure the proper working of cleaning systems, to control the environmental levels, to assess environmental exposure, to evaluate health risks associated with different pollutant sources, and to identify the relative importance emission sources into the atmosphere in order to adopt

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0160-4120/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envint.2009.09.006

the necessary measures to protect the environment and the human health. In that context, ambient air monitoring is an essential issue to estimate pollutant emissions such as PCDD/Fs and mercury.

In humans, most PCDD/F and heavy metal body burden comes from the ingestion of contaminants (Parzefall, 2002; Llobet et al., 2008). Some physiologically based pharmacokinetic models have been applied to predict the PCDD/F levels in human tissues (including blood) on the basis of the ingestion of PCDD/Fs through food and human milk. These models are useful not only to investigate past, present, and future trends, but also to help in human health risk assessment due to PCDD/F intake. Using one of these models, Aylward and Hays (2002) reported that absorbed intake levels of 2,3,7,8-TCDD decreased from 1972 to 2002 by more than 95%. Notwithsatnding, and taking into account that food contamination is a direct consequence of the bioaccumulation of pollutants through the food chain, it is important to assess the contribution of the different activities to the environmental concentrations.

In contrast to incinerators, only a few studies have been published on PCDD/F emissions from crematories (Hutzinger and Fiedler, 1993; Takeda et al., 2000, 2001; Luthardt et al., 2002; Wang et al., 2003). Although human cremation is an increasing practice, the number of studies regarding the potential risks derived from crematory emissions is very scarce in relation to the most dangerous compounds (PCDD/Fs and mercury), being even non-existent for other compounds such as $NO_x$, CO, $SO_2$, PAHs, etc. In this context, further research on crematories is necessary. In the following sections the information currently available regarding this issue is presented and discussed.

### 1.1. Incinerators

In recent years, incineration has become one of the most widely used alternatives for waste management. This process is considered by regulators as a strategic option for waste reduction and disposal (Richter and Johnke, 2004; Kollikkathara et al., 2009). In comparison with other waste treatments, incineration presents advantages such as volume reduction, energy recovery, and elimination of pathogen agents (Kuo et al., 2008). However, the public opinion of most developed countries is frequently concerned about the installation of municipal, hazardous, and medical waste incinerators (Domingo, 2002; Singh and Prakash, 2007). Among the pollutants emitted by waste incinerators, PCDD/Fs have generated a lot of controversies (Schuhmacher and Domingo, 2006), mainly because they are among the most toxic environmental compounds (Kogevinas, 2001; Steenland et al., 2004; Mandal, 2005). Although PCDD/Fs, usually referred to as dioxins, are generally produced in many combustion processes (Kulkarni et al., 2008; Zheng et al., 2008; Shen et al., 2009), until a few years ago, incinerators were catalogued as one of the most important sources of toxic emissions, not only PCDD/Fs but also heavy metals (Shibamoto et al., 2007; Zheng et al., 2008). Therefore, incineration has received prolonged special attention, and the concern raised has had significant implications in current regulatory practices (Franchini et al., 2004; Lonati et al., 2007; Kim et al., 2008). Intensive studies have been conducted on various PCDD/F emission sources, including the waste combustion sources, chemical-industrial sources, and other thermal sources.

The installation of modern cleaning technologies to comply with the maximum emission level of PCDD/Fs, established by the European Directive in 0.1 ng I-TEQ/$Nm^3$ has substantially minimized the environmental impact of incinerators (Glorennec et al., 2005). Although incinerators have traditionally been pointed out as important air emitters of PCDD/Fs (Quass et al., 2004; Kim et al., 2008; Wang et al., 2009), there are many other industrial (cement kilns and power plants) and diffuse (vehicle emissions, domestic coal/wood combustion and natural fires) sources also emitting these pollutants (Fuster et al., 2001).

A number of recent studies have demonstrated that emissions of toxic pollutants from modern municipal solid waste incinerators (MSWIs) have a relatively low environmental impact in comparison with other alternatives of waste disposal or different industrial activities (Domingo, 2002; Schuhmacher and Domingo, 2006; Kao et al., 2007). Although human exposure to PCDD/Fs mainly occurs via food consumption, and more specifically through the ingestion of fatty foodstuffs (Domingo and Bocio, 2007; Llobet et al., 2008), environmental exposure to PCDD/Fs must not be neglected. Among the different pathways of direct exposure to these pollutants, inhalation seems to be the most important route (Nadal et al., 2004).

### 1.2. Crematories

Although crematories of human beings are also combustors, from a legal/regulatory point of view, these facilities are not considered as incinerators. A human crematory contains one or more combustion units known as cremators, used solely for the cremation of human bodies within appropriate containers. With respect to the potential PCDD/F emissions from crematories, it must be noted that these compounds are formed during combustion processes when chlorinated products such as plastic are burned. In crematories, these plastics may be present as prosthetics or as part of the container. The body also contains a percentage of chlorine, and thus cremation produces PCDD/Fs. Moreover, when waste wood is burnt, the level of PCDD/Fs in the flue gas emissions has been reported to be significantly lower than that derived from other sources (Lavric et al., 2004). Even non-treated wood contains small amounts of chlorine. It means that PCDD/F emissions might be only minimized, but not eliminated (Salthammer et al., 1995). PCDD/Fs are created on particles of soot that enable the hazardous chemical to travel from the incineration site. These particles will eventually settle out onto land (Suzuki, 2007). Contaminated grass enables PCDD/Fs to enter the food chain and it will ultimately be consumed by humans and stored in body fat.

Mercury is another environmental pollutant usually emitted during incineration (Llobet et al., 2002; Ferré-Huguet et al., 2007; Muenhor et al., 2009). In crematories, mercury enters the process because it is present in the body being cremated. Although mercury is only the thirty-sixth most abundant element in the body (at 6 mg for the average body), there is a source of mercury that means serious concern. Fillings made with dental amalgam contain more than 0.5 g of mercury. This metal will leak from these fillings because of mercury's low vapor pressure and add to the mercury levels already present in the body. The intense temperatures of cremation cause the mercury present in the fillings to volatilize, and added to the mercury present in the body may give place to a release of relatively large amount of this toxic metal. Studies have found as much as 200 μg/$m^3$ of mercury during the cremation process of a body with dental amalgam fillings (DEFRA, 2003).

Cremators are usually made of high-grade steel plate and lined inside with heavy refractory tile or brick. Most cremators have a variety of automatic controls and use gas for heating the cremator. As a result of the Clean Air Act of 1990, the US EPA first classified crematories as medical waste incinerators, and later as OSW (“Other Solid Waste”) incinerators. After an intensive, costly and aggressive testing project in 1999 on working crematories that covered most types of emissions, including particulate matter, carbon monoxide, and mercury, done jointly with the Cremation Association of North America and reviewing information presented, the US EPA decided not to regulate human or animal crematories. As a result of the US Cremation Association's meeting with the US EPA in November 1991, it became known that the original regulations proposed for crematories were based on no actual test data. This inspired the US Cremation Association to have substantial testing performed to increase everyone's knowledge base. This testing was completed in 1999 and the data became US EPA's foundational information in their national emissions inventory (CANA, 2009).