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Review article

Toxic emissions from crematories: A review

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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.

Contents

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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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).

Among the concerns raised by crematories, there does not appear to be any risk to the environment or the operator under normal conditions, when cremating someone who has been treated with radiation therapy. Generally, radioactive implants are removed prior to the cremation. Cremation of radio-nuclides, or radioactive "seeds," that might remain in a body does not pose a problem due to the rather small number of cremations that occur annually and their relatively short half-life. With respect to the possibility that any element in human remains that would be harmful to the environment as a result of cremation it seems the response is no. Human remains consist of 85% moisture, which vaporizes during the cremation process, 10% combustible solids which release approximately 1000 BTUs (British Termal Unit) per pound and transfer from a solid to vapor state, and 5% non-combustible solids which absorb heat and energy from the cremation process and remain as solids (bone fragments and ash materials) when cremation is completed. The 5% non-combustible solids are usually returned to the family (DEFRA, 2003; CANA, 2009).

In fact, a crematory furnace consists of a refractory chamber in which the mortal remains to be cremated are placed. The coffin is forwarded into the furnace by a conveyor fixture. In the so-called "cold type" furnaces, the coffin is placed inside at a temperature of about 300 °C. In the "warm types", the temperature is 800 °C or higher. The cremation is carried out in furnaces which are fired using oil or natural gas. There are also some which run on electricity. In more modern installations the remains are transported to a post burning chamber located beneath where they are post-fired (minimum temperature 850 °C). The cremation time is about 1.2–1.5 h in the warm types and lasts for 2–2.5 h in the cold types. The average volume of waste gases is approximately 1200 Nm^3/h for gas and oil fired furnaces and approximately 600 Nm^3/h for electrically heated furnaces. The waste gases from the muffle are transported via the post-firing chamber and the recuperator and are subsequently purified by cyclones and fabric or electro filters (EDI, 2006).

In Europe, crematoria are certainly not of high relevance for the total emission of PCDD/Fs. The European Dioxin Air Emission Inventory, whose results were published by Quass et al. (2004), reported a 1985 upper estimate of 28 g I-TEQ/year, and a 2005 estimation of 13 (minimum) and 22 (maximum) g I-TEQ/year from cremation (incineration of corpses). The emissions corresponding to the total of sources considered (g I-TEQ/year) were 13,690 for 1985, and 1963–3752 for 2005. Taking this into account, up to now, the data from crematoria suggest that in most cases these installations may be disregarded. However, from the local view crematoria without or low quality flue gas cleaning might have adverse environmental impact. Therefore some spot-check measurements might be necessary to assess the possible emissions and confirm the currently available data, especially in those countries which did not provide any data. In a PCDD/F emission inventory for the Tarragona Province (Catalonia, Spain) that we performed in 1999, a total of 2.24 g I-TEQ/year was found, with a contribution for crematoria of only 0.00029 g I-TEQ/year (Fuster et al., 2001).

On the other hand, for years, The Cremation Association of North America (CANA) has witnessed the concern surrounding cremating human remains, and the corresponding release of primarily two emissions: particulate matter (PM) and mercury. PM can be defined as solid particles suspended in a gas as a byproduct of all combustion processes, including cremations. PM emissions are released into the environment in many ways, including through residential and commercial fuel-based heating, cars, trucks, restaurant grills and fireplaces. None of these sources of PM have any emission controls to reduce, monitor or limit PM emissions, while crematories have emission controls as part of their design to limit the amount of PM entering the atmosphere (CANA, 2009). On the other hand, mercury is derived from the use of silver amalgam in dental fillings that is released into the environment during the cremation process.

2. PCDD/F emissions from crematories

In recent decades, PCDD/F emissions from refuse incinerators became a serious problem in a number of developed countries. Numerous studies focused on estimating the quantity of PCDD/Fs emitted from municipal and industrial waste incinerators have been published. In contrast, in those countries with a notable ratio of cremation of human bodies, until recently emissions of PCDD/Fs from crematories were, in fact, unknown. For example, in Japan, where a 98.8% of dead bodies were cremated in 1997 (the highest percentage in the world), and with 1607 crematories in operation at that time, only a few studies have been carried out on PCDD/F emissions from crematories.

The reports about PCDD/F emissions from crematories in the world are really limited (Hutzinger and Fiedler, 1993; Federal States Pollution Control Committee, 1994; Eguchi et al., 1996; Fiedler, 2006). In Japan, Eguchi et al. (1996) reported the concentration of PCDD/Fs from a crematory to be 0.14–2.56 ng TEQ/Nm^3. This was less than the concentration of PCDD/Fs from crematories in Germany, 8 ng TEQ/Nm^3 found by Hutzinger and Fiedler (1993). In 1994, a working group of a subcommittee of the German Federal State Pollution Control Committee reported the levels of PCDD/Fs for 13 crematories from Germany. It was found that the concentration of PCDD/Fs from those crematories was 0.1–14.4 ng TEQ/Nm^3, and almost all of them were more than 1 ng TEQ/Nm^3 (The Working Group of Subcommittee, 1993).

Since in Japan, about 99% of dead bodies were cremated in a considerable number of crematories, it seemed necessary to investigate crematories of various types to estimate the quantity of PCDD/Fs emitted from these facilities. Takeda et al. (2000) measured the concentrations of PCDD/Fs in emission gases from 10 Japanese crematories. The relationship between PCDD/Fs and several factors such as structure, equipment, and operational state of the crematory were assessed. Furthermore, emission of PCDD/Fs from all Japanese crematories was estimated. The most relevant results were the following: 1) total concentration of PCDD/Fs from a crematory was 2.2–290 ng/Nm^3, and TEQ concentration was 0.0099–6.5 ng TEQ/Nm^3, 2) the concentration of PCDFs was higher than that of PCDDs, especially tetrachlorodibenzo-*p*-furans (T4CDFs), being 2,3,7,8-T4CDF detected in almost all samples, 3) for a homologue pattern of PCDFs, the concentration of T4CDFs was high, while that of the higher chlorinated compounds was low. For that of PCDDs, two patterns were identified: (a) a mountain shape pattern with peaks of hexachlorodibenzo-*p*-dioxins (H6CDDs), which was similar to the typical pattern of waste incinerators, and (b) a pattern the same as the PCDFs pattern, with decreasing concentrations when increasing the degree of chlorination, 4) the total concentration of PCDD/Fs from crematories whose dust concentration was less than 50 mg/Nm^3 tended to be low, 5) the total concentration of PCDD/Fs was highest in the first 20 min from the start, 6) it was found that sex and age of dead body did not affect the concentration of PCDD/Fs, 7) the existence of a dust collector, temperature of the secondary combustion chamber, and the number of main combustion chambers connected to a secondary combustion chamber affected the concentration of PCDD/Fs, and 8) the total amount of PCDD/Fs emitted from crematories in Japan was estimated to be 8.9 g TEQ/yr. Takeda et al. (2000) concluded remarking that the number of data was not enough to grasp the state of PCDD/F emissions from crematories in Japan.

In a subsequent study of the same research group, PCDD/Fs and co-planar PCB concentrations in flue gases from 17 Japanese crematories were measured in fly ashes and bottom ashes (mainly bone) from several crematories to assess the state of PCDD/F emissions from those facilities (Takeda et al., 2001). The effects of several factors were discussed to prevent PCDD/F emissions from crematories. Total concentration (normalized by 12% O_2) of PCDD/Fs ranged from 4.9 to 1200 ng/Nm^3, and TEQ concentration ranged from 0.064 to 24 ng TEQ/Nm^3. According to the results of that study, these measures for existing crematories were

recommended in order to reduce PCDD/F emissions: 1) keeping the temperature at 800 °C in main/secondary chambers during a whole cremation, and 2) lowering the temperature in the dust collector. For newly installed crematories, Takeda et al. (2001) suggested the following measures to prevent PCDD/F emissions, including the measures for existing ones: 1) connecting one secondary chamber to one main chamber, 2) installing the high efficiency dust collector and reducing dust concentration to less than 0.01 g/Nm^3, and 3) installing the sampling point for monitoring of PCDD/Fs.

In Germany, Luthard et al. (2002) analyzed the concentrations of PCDD/Fs and PCBs, and estimated total TEQ, in flue gas samples from eight different sources (two municipal waste incinerators (MWI), one hazardous waste incinerator (HWI), two sintering plants, one cement kiln, and two crematories). The highest TEQ values were found at crematory No. 2, the sintering plants, and at the MWI with older technology. TEQ emissions below the 0.1 ng/Nm^3 limit were found at the modern MWI, the HWI, and at the cement kiln.

In a previous study also conducted in Germany by Hutzinger and Fiedler (1993), PCDD/F concentrations of about 8 ng TEQ/Nm^3 were detected in the stack flue gases of crematories, while in the UK, a study conducted by the Warren Spring Laboratory found a mean PCDD/F concentration of 46 ng TEQ/Nm^3 (11% oxygen) for the cremation process (Eduljee and Dyke, 1996). In the USA, PCDD/F emission rate (expressed as TEQ) for the crematory source was found about 9.1 g TEQ per year (US EPA, 2000), which was in the range of that found in the UK: 1–35 g TEQ per year (Eduljee and Dyke, 1996), but higher than that reported in Japan: 1.3–3.8 g TEQ per year by Takeda et al. (2001). The wide range of PCDD/F concentrations arising from various crematories was believed to be due to their intrinsic differences in operation conditions, air pollution control devices, and involved incinerating materials (Takeda et al., 2001).

In general, total PCDD/F emissions from crematories are relatively small compared with those from MWIs. For example, in the study conducted in Japan by Takeda et al. (2001) the crematory emission accounted for only 0.13–0.29% of that emitted from MWIs. However, it should be noted that most assessed crematories were equipped with a low stack, and were situated in the proximity of residential areas. In particular, most of them did not adopt any air pollution control device to eliminate PCDD/F emissions from stacks. Based on these, it could be expected that PCDD/F emissions from a crematory might significantly affect its surrounding environment.

Recently, the cremation ratio has increased dramatically in many countries (Santarsiero et al., 2005; ECN, 2008). In Taiwan, the cremation ratio was expected to increase from 66.9% in 2000 to 85.0% in 2005 (Wang et al., 2003). In the USA, the cremation ratio also increased significantly from 15.2% in 1987 to 25.0% in 2000, and was expected to reach 37.0% in 2010 (US EPA, 2001). Based on these data, it is expected that crematories will play an important role on PCDD/F emissions not only in countries such as Japan or Taiwan, but also in many other countries. In addition to PCDD/Fs, PCBs and PAHs, as well as total suspended particles (TSP) from crematories might also be a cause of problems to human health.

Wang et al. (2003) characterized PCDD/F emissions from Taiwanese crematories and assessed their impacts on the surrounding environment. Two crematories (C) located in southern Taiwan were investigated, including C1 with no air pollution control device installed, and C2 with a bag filter. The mean PCDD/F emissions (11% oxygen) from the stacks of Cl and C2 were 2.36 and 0.322 ng I-TEQ/Nm^3, respectively, while mean emission factors for C1 and C2 were 13.6 and 6.11 μg I-TEQ/body, respectively. The removal efficiency of the bag filter on PCDD/Fs was 55.1%. The estimated PCDD/F emission rate for all crematories in Taiwan was 0.838 g I-TEQ/year. In an emission inventory of PCDD/Fs in Taiwan, a total of 67.25 g I-TEQ of PCDD/Fs released annually was estimated (Chen, 2004). Secondary copper smelting accounted for more than 39% of the total PCDD/F emissions, being higher than those from all waste incinerators combined (23.7%). Based on that inventory, PCDD/F emissions from crematories would be relevant, as they were 227% and 22.4% of the annual emissions from all medical waste incinerators and MWIs, respectively. To assess the impact of PCDD/F emissions from a crematory to the surrounding environment, ambient air samples were collected from the downwind site of C1 with the maximum ground concentration (Wang et al., 2003). The estimated maximum ground concentration at the downwind site of C1 (0.521 pg I-TEQ/Nm^3) was much higher than that found at the background, rural area, residential area, urban area, and industrial area (0.006, 0.023, 0.052, 0.093, and 0.190 pg I-TEQ/Nm^3, respectively). The authors indicated that the high I-TEQ concentration found in the vicinity of C1 might be due to the fact that the involved crematory had a low stack, being installed with no air pollution control devices. It was concluded that PCDD/F emissions from a crematory did significantly affect its surrounding environment, and therefore, a proper control strategy was essential in order to eliminate PCDD/F emissions from crematories. A summary of the most relevant results corresponding to some of the above studies is shown in Table 1.

PCDD/F emissions from well-maintained cremators were measured (Edwards, 2001) and found to be much lower than previous measurements made in the early 1990s. The average emission was 61 ng I-TEQ per cremation, giving a UK total PCDD/F emission from crematoria of 0.027 g I-TEQ, which meant 0.008% of the UK total emission of 325 g I-TEQ. From measurements made in the early 1990s, about 5% of UK emissions to air of PCDD/Fs were attributed to crematoria. Recent emission levels were similar to PCDD/F emission limits in Waste Incineration Directive 2000/76/EC. Although that Directive does not apply to crematoria, its emission limits indicate what good exhaust gas treatment can achieve.

3. Mercury emissions from crematories

In addition to PCDD/F emissions from crematories, another environmental aspect that has received particular attention is the release of mercury. This element is liberated both because dental amalgams that are unstable at cremation temperatures (650–700 °C), and because of the free mercury metal is highly volatile (Nieschmidt and Kim, 1997). In Switzerland, Rivola et al. (1990) estimated that mercury contamination due to cremation varied in 1988 between 45.8

Table 1
A summary of data concerning air emissions of dioxins and furans (PCDD/Fs) from crematories in different countries.

Country	Emissions of PCDD/Fs	Remarks	Reference
Germany	8 ng TEQ/Nm^3	–	Hutzinger and Fiedler (1993)
Germany	0.1–14.4 ng TEQ/Nm^3	In almost all the 13 crematories assessed PCDD/F emissions were higher than 1 ng TEQ/Nm^3	Federal States Pollution Control Committee (1994)
United Kingdom	46 ng TEQ/Nm^3	1–35 g TEQ/year	Eduljee and Dyke (1996)
Japan	0.0099–6.5 ng TEQ/Nm^3	Total concentrations in 10 crematories: 2.2–290 ng/Nm^3	Takeda et al. (2000)
Japan	0.064–24 ng TEQ/Nm^3	Total concentrations in 17 crematories: 4.9–1200 ng/Nm^3	Takeda et al. (2001)
Germany	0.24 (Crem. 1) and 3.71 (Crem. 2) ng TEQ/Nm^3	Six industrial plants and two crematories were assessed. Among the 8 facilities, the highest TEQ values were found at Crem. 2	Luthardt et al. (2002)
Taiwan	2.36 (Crem. 1) and 0.322 (Crem. 2) ng TEQ/Nm^3	The mean emission factors for Crem. 1 and Crem. 2 were 13.6 and 6.1 μg I-TEQ/body, respectively	Wang et al. (2003)

and 79.0 kg, based on both data from the sample analyzed and the fact that 55.5% of Swiss funerals were cremations, the average age of death was 73, and that 70% of the people of that age retained some of their teeth. According to these authors, mercury contamination by cremation comprised 0.61–1.53% of the total mercury contamination produced by all waste incineration methods in that country. Also in Switzerland, Matter-Grütter et al. (1995) determined the amount of mercury released at two crematoria. A total of 60 mercury "output" calculations were carried out by the Swiss Material Testing Institute. The amount of mercury initially present ("input") in the dentitions of 54 deceased persons was assessed from their post-mortem dental radiographs and by clinical examination. The correlation between the "input" and the "output" was 0.93, irrespectively of the age at death. However, the "input" was calculated to be 1.8 times higher than the "output" for the deceased people with amalgam restorations. In a blind study, the difference was 1.3 times. The main source of mercury was undoubtedly the amalgam restorations. The amount of mercury recorded during the cremation of 88% of the deceased people without amalgam restorations was under the accepted level of 200 μg/m^3. However, in three cases, the amount of mercury was slightly higher than 200 μg/m^3. In contrast, the amount of mercury recorded during the cremation of only 18% of the deceased people with amalgam restorations was less than the accepted level of 200 μg/m^3. The amount of mercury contamination during cremation as a result of amalgam fillings was so low that no additional preventive measures were required at those crematoria.

In Japan, Yoshida et al. (1994) measured the amount of mercury released at three crematories. The concentration of atmospheric mercury at those three facilities ranged from 4.3 to 19.7 ng/m^3. This rank was nearly identical to the levels found in the control (university campus) area, being also similar to the general levels of atmospheric mercury in the country. The amount of mercury released from one of the crematories was subsequently estimated using official published statistical data in Japan and calculated as follows: sigma[(age specific number of dead that were cremated) × (the number of restored teeth by age category) × (mercury content per amalgam filling (0.6 g))] × (prevalence rate of restoration with amalgam). The amount of mercury released from this crematory was estimated to be approximately 9.4 kg per year, or a daily release of 26 g into the ambient air, which indicated that mercury released by cremation was similar to that from other man-made sources.

A number of reports have been published giving estimates on the amount of mercury released into the atmosphere by crematoria and the concentration of soil mercury found around crematoria in the USA and England (Mills, 1990; Kunzler and Andree, 1991; Basu and Wilson, 1991; Burton, 1991; Hogland, 1994). As in other countries, in New Zealand, a high percentage of deaths are followed by cremation and this figure is expected to rise in the future. This increasing use of cremation as the method of corpse disposal, coupled with the fact that each amalgam restoration is approximately 50% mercury, implied that a significant amount of mercury was being emitted into the environment every year. In that country, Nieschmidt and Kim (1997) using cremation data available from the International Cremation Statistics (ICS, 1992) and the calculations of Burton (1991), estimated emissions about 22.8 kg of mercury per year, and that global annual mercury emissions would total 6962 kg. Globally, atmospheric mercury emissions from crematories of this magnitude would account for about 0.8% of total anthropogenic mercury emissions (based on the estimates of Nriagu and Pacyna, 1988). Recently, Santarsiero et al. (2006) reported some preliminary results concerning mercury and total particulate matter emissions during three cremation processes in Italy. A mercury concentration ranging from 0.005 to 0.300 mg/m^3 and a mercury emission factor ranging from 0.036 to 2.140 g/corpse cremated were obtained. The total particulate matter concentration range was from 1.0 to 2.4 mg/m^3.

It must be noted that mercury (as well as other pollutants) emissions from crematoria are not covered by the European Union regulations. Currently, matters of crematories are the responsibility of local Authorities. However, mercury emissions have been the subject of the OSPAR Recommendation. In fact, the OSPAR document, namely OSPAR Recommendation 2003/4 on Controlling the Dispersal of Mercury from Crematoria (OSPAR, 2003) in the OSPAR Convention Area identified crematoria as producing a significant source of mercury in the environment and listed various options, in terms of the best available technologies (BAT) to reduce and control mercury emissions. The reports on emissions made by parties involved with this recommendation, will provide an indication of the effectiveness and if further action is needed. Future trends in mercury emission are difficult to predict since they are strongly affected by the following variables: the number of cremations per year, the number of amalgam fillings and the related mercury, and the content present at cremation. Therefore, for the assessment of current and future mercury emission factors the following must be taken into account: the amalgam fillings and related dentistry practices used in the past, those currently used and those to be used in the near future, and the distribution of dental amalgams within the population (Santarsiero et al., 2006).

Recently, in the 9th International Conference on Mercury as a Global Pollutant (ICMGP) held in Guiyang, China, Reindl (2009) concluded that there were significant uncertainties in North American data, as few studies existed concerning mercury emissions from crematories. North American demographics may be different than European for restoration sizes, composition and number. An increase in emissions for the next several decades can be expected followed by a decrease. Reindl (2009) recommended collecting information on the amount of mercury released per cremation, mass balance, air, ash, deposited on crematorium surfaces and speciation of air emissions, which is essential for regulators.

The AEAT study for PCDD/Fs above cited (Edwards, 2001), included also measurements of mercury emissions 18 crematories in the UK. Most mercury in bodies is in dental amalgam fillings, and as the number of fillings varies from person to person, a wide variation of mercury emissions could be expected. The measurements showed 6 crematories with very little mercury and a considerable variation in emissions from the other crematories. The average emission across all the crematories was 0.9 g of mercury per crematory, an amount that was less than the calculated emission factor of 3 g per crematory that was used to estimate UK mercury emissions from crematoria, and reported in the National Atmospheric Emission Inventory (DEFRA, 2003). The calculations gave a range of mercury emissions from crematories as 5.3%–15.7% of UK mercury emissions to air in 2000. Crematoria emissions in the UK are expected to increase from 0.4–1.34 tonnes in 2000 to 0.68–2.2 tonnes in 2020 unless gas cleaning of exhausts is introduced (DEFRA, 2003).

4. Occupational and environmental health effects from crematories

Information on occupational exposure to individuals working in crematories is particularly scarce. To the best of our knowledge, only a study in the UK has examined this potential exposure (Maloney et al., 1998). By measuring the levels of mercury in hair, it was concluded that exposure to mercury vapor by workers in crematoria was rather low compared with others who were occupationally exposed to this element. Of the 97 crematoria workers assessed, 3% had concentrations higher than 6 μg/g, generally considered as a tolerable concentration for mercury in hair. According to their results, the authors considered that there was sufficient evidence to warrant emission monitoring and control in crematoria workers.

On the other hand, and related with environmental exposure to emissions around crematories, Dummer et al. (2003) investigated the risk of stillbirth, neonatal death, and lethal congenital anomaly among babies of mothers living close to both incinerators and crematories in Cumbria, north west England, 1956–1993. A significant increase was noted during this period on the risk of stillbirth closer to crematories. The risk of

anencephalus was also significantly increased during the same period. Although most (92%) cases of anencephalus were stillborn, the significantly increased risk of stillbirth remained after exclusion of anencephalus cases from the analysis. From 1972 onwards there was an increased risk of all other congenital anomalies, excluding neural tube defects and heart defects, with increasing proximity to crematoriums, which was significant for the period 1983–1993. These findings remained significant after exclusion of the most influential births. It was concluded that threw was an increased risk of lethal congenital anomaly (specifically spina bifida and heart defects) in relation to proximity to incinerators, and an increased risk of stillbirth and anencephalus in relation to proximity to crematoriums (Dummer et al., 2003). However, a causal effect from the statistical associations could not be inferred, since as it was noted there are a number of factors (medial advances, clinical characteristics, etc.), that may also affect the results, which is one of the main drawbacks or limitations of all geographical epidemiological studies. On the other hand, since incinerators and crematories are sources of harmful substances, it is worth to keep investigating their potential effects on public health.

5. Conclusions

An exhaustive revision on the scientific literature by means of the databases PubMed (http://www.ncbi.nlm.nih.gov/pubmed/), Scopus (http://info.scopus.com/) and Scirus (http://www.scirus.com/) using crematories/crematoria, toxic emissions, dioxins and furans, mercury, and health risks as searching terms, has detected only a scarce number of published studies. With respect to organic emissions from crematories, PCDD/Fs have been the most investigated. In comparison with PCDD/F emissions from waste incinerators (municipal, hazardous and medical), those corresponding to crematories are significantly lower. However, if the facilities are installed near nuclei of population, any specific filter is used, and the high of the stack is relatively low, human health risks should not be discarded, and a monitoring program should be carried out. In relation to mercury, which is a highly volatile element, to date the most important source has been dental amalgams containing mercury, which are unstable at cremation temperatures. In recent decades, serious efforts have been made in most developed countries in order to reduce the levels of environmental mercury. In this sense, if mercury emissions from crematories are not properly controlled, these facilities could mean a relatively important source of atmospheric pollution. Another relevant aspect of toxic emissions of crematories is the noted lack of general regulations of these emissions. For example, neither the European Union nor the US EPA has established specific recommendations for crematories.

In summary, because of cultural and other reasons, in recent years the cremation ratio has considerably increased in many countries, a trend that is expected will continue in the near future. Therefore, we think that crematories must also be among the facilities whose emissions should be specifically regulated and monitored.

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