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Environmental and health risks related to waste incineration

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Abstract

The article presents a mini review of the published research focused on understanding environmental and human health impacts nearby waste incineration plants. We found no studies indicating that modern-technology waste incineration plants, which comply with the legislation on emissions, are a cancer risk factor or have adverse effects on reproduction or development. There are several factors in favor of this affirmation: (a) the emission levels of the plants currently built in the developed countries are several orders of magnitude lower than those of the plants in whose environments epidemiological studies have been carried out and which have found some kind of negative association in terms of health; (b) risk assessment studies indicate that most of the exposure is produced through the diet and not by a direct route; and (c) monitoring dioxin level studies in the population resident in the environment of incineration plants did not reveal increases of these levels when compared with a population living in reference areas. A necessary condition for the development of a waste incineration plant is to generate the conditions to prevent any impact that activates or potentially carries damage or risks to the environment and, in particular, to health. This makes it imperative to use a preventive strategy through the implementation of a previous environmental impact assessment and the establishment of emissions standards and an emissions monitoring program in order to ensure the prevention of environmental damage.

Keywords

Waste management, waste incineration, health effects, environmental exposure

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Introduction

As long as society sustains a linear economy of extraction of resources, production, consumption and disposal, an increasing amount of waste will be generated every day.

The generation of waste and the collection, processing, transport and disposal of it—the process of "waste management" (WM)—is important for both the health of the public and aesthetic and environmental reasons. Since waste is anything discarded by an individual, household or organization, waste results a complex mixture of different substances, only some of which are intrinsically hazardous to health.

WM is now tightly regulated in most countries. Solid urban waste incineration (WI) started at the end of the 19th century. After the crisis of the 1930s, WI declined due to the impoverishment of its energy content, and it was not until 1960s–70s that it became a common tool for WM, as technology evolved. The significant reduction of emissions to nearby communities has reduced concerns that the resulting products may have potential impact on the environment and human health.

Today, WI is a technology widely used in developed countries. Thus, in 2015 there were 507 WI plants in 25 European countries. A significant value of WI lies in the development of the technology of thermovaluation or Waste to Energy, widely used in Japan with 210 plants, Germany with 121 plants, France with 126 plants, the rest of Europe and Russia with 276 plants, China with 225 plants, the rest of Asia with 62 plants and the USA with 99 plants, giving value to 240 million tonnes of annual non-recyclable waste to produce electricity (CEWEP, 2015; Comisión Europea y Ministerio de Medio Ambiente y Medio Rural y Marino de España, 2011; Eurocities, 2017; Eurostat, 2015; ISWA, 2013; Perona, 2016).

However, certain sectors from civil society express some concerns on the impact of WI on the environment and the population living near WI plants.

In 1996 the World Health Organization (WHO) published the document "Waste incineration" in which incineration was defined as "an hygienic methodology to reduce the volume and weight of the waste as well as its pollutant potential" and "Is one of a number of waste disposal strategies which can be used to ensure that wastes are handled in an environmentally suitable manner" (Haukohl et al., 1996).

Thereafter, a WHO exposure assessment expert group suggested that priority pollutants should be defined on the basis of

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toxicity, environmental persistence and mobility, bioaccumulation and other hazards such as explosivity (WHO, 2000).

The incineration process may result in three potential sources of exposure to the environment: (a) atmospheric emissions, (b) ashes and slags, and (c) through cooling water. Accepting that the ashes and cooling water are properly managed and arranged, atmospheric emissions are the only source of danger as people's route of exposure. The concern related to these emissions is focused on some well-known contaminants: particulates, dioxins and furans and other carcinogens such as polycyclic aromatic hydrocarbons (PAHs), whose health effects are quite well known.

The aim of the present study is to review the health risks linked to municipal solid waste incineration practices within and across different countries and identify key issues. Although incineration plant technology has evolved significantly over time, reports associated with "old fashioned" plants were not excluded since they present evidence that must be taken into account in less developed countries at the time of evaluating and taking decisions to incorporate incineration plants into their waste management programs. So, we believe the present work may help to gain a clearer picture of the situation on the ground and identify areas of improvement.

Methods

The scientific literature was scrutinized through computerized literature searches using the Google Scholar search engine and the PubMed Library. The keywords to search the database included municipal solid waste incineration, environmental exposure, environmental disease and health risks as well as various combinations. Literatures selected must meet the following overall criteria: (a) the objective of the study is focused on the consequences of incineration of municipal solid waste; (b) the article must be written in English or Spanish; and (c) the article is published in a peer-reviewed journal or published by government departments, non-governmental organizations such as ISWA and multilateral agencies such as WHO. In addition, articles were traced through references listed in previous reviews. The papers included in this review include those published between 1999 and mid-2018. It is interesting to note that although the category "any language" was always employed, the search yielded almost twice the number of references when the search was formulated in English than in Spanish. Our initial search yielded a total of 12,100 research articles. In successive iterations, articles focused on subjects such as history and technology, articles mentioning health risks only in passing as well as general articles or those focusing on limited categories of waste were also excluded. Remaining articles were analyzed individually to assess if they focused on our primary interest. Hence the article selection followed an iterative process in which non-relevant articles were excluded from subsequent searches.

Health risks

Briefly, let us remember that exposure to particles—both in the short and long term—is detrimental to health. Long-term exposure increases the risk of death, especially from cardiovascular disease and lung cancer. Short exposure impacts have cardio-respiratory effects including increased heart attack mortality and respiratory disease. Threshold values have not been identified in either of the two situations so it is accepted that any increase in the concentration of particles has an effect on health. So the critical step is not to say that an effect is possible but to estimate the weight of that effect. The pathological mechanisms are also not known in detail, although various processes involved have been identified and studied. It is interesting to note that particle size appears to be more relevant than its composition, but this is still a matter of discussion (World Health Organization, 2006).

It is important to remember that in order to reduce particulate emissions some years ago equipment was designed to retain particles known as PM_{10} (expressed in $\mu g/m^3$), essentially selecting all particles with an aerodynamic diameter equal to or less than 10 microns; that is, those capable of passing through the upper airways (nostrils, mouth, pharynx and larynx) and being deposited in the lungs. Therefore, PM_{10} includes $PM_{2,5}$ particles which represents the fraction of the aerosol with high probability of depositing in the pulmonary zone of gaseous exchange and nanoparticles (less than 0.1 micron or 100 nm, $PM_{0,1}$). In addition, while it is correct to say that nanoparticles are probably the largest contributor to the number of particles in the air, their contribution to the local mass of particles is low and hardly reflected in the PM_{10} or $PM_{2,5}$ registered. Nor is it accurately known how it is reflected in its impact on health.

We also consider it advisable to summarize some concepts related to carcinogens, a denomination that includes any substance that causes cancer.

For the purposes of risk assessment, carcinogens can be divided into two groups according to their mechanism of action. The first group is that of genotoxic carcinogens, those that induce cancer by a mechanism involving the substance, or a metabolite of it, which reacts directly with the genetic material of the cells (DNA) producing a mutation. This process is called mutagenicity and is assumed to have no threshold: any exposure is associated with increased risk. Examples are aflatoxins, benzene and polycyclic aromatic compounds. The second group is non-genotoxic carcinogens, which induce cancer by non-mutagenicity-based mechanisms. In these cases different mechanisms are involved and it is accepted that the effects have a threshold based on the precursor toxicological effect. Examples are estrogens and dioxins.

Incineration impact on environmental and human health

In 1998, 2000 and 2007, the World Health Organization (WHO) convened expert meetings on WM. In the first two, it focused its attention on the impacts of management problems and the impact of landfills, without specifically including incineration-related aspects. In the third, under the understanding that WM becomes more complex over time and that in some communities there was concern about the possible health and welfare effects of exposure to waste and management products, the scientific information available on WM and its relationship with community health was reviewed. In addition, the situation of key European countries was analyzed within the scope of exploring how to give better support to the authorities responsible for WM (World Health Organization, 2007).

With regards to incineration facilities it was concluded that:

> Incinerators have been operating in many European countries since the 1960s and their technology has evolved over time, in general with a reduction of emissions to nearby communities. As to the possible health effects of incinerators, reasons for concern are inhalation of airborne pollutants resulting from combustion and from incomplete combustion, consumption of contaminated foods and water, or contact with contaminated soil. Information on the presence of hazardous agents in the vicinity of an incinerator is not easily translated into useful exposure measures. Compared to landfills, fewer epidemiological studies are available. While some positive studies exist, the evidence is, overall, not conclusive to establish the occurrence and magnitude of risks. As in landfill studies, increases in relative risk are difficult to detect because they are generally caused by long-term low-level exposures. Studies pointing to an increase in soft tissue sarcomas (STS) and non Hodgkin's lymphomas (NHL) support a possible etiologic role of 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8 T4CDD). The evidence is inadequate to draw conclusions that can be used to determine optimal policy choices on incineration: relatively few good quality studies exist and they refer mostly to old generation incineration plants—an important distinction, as stack emissions from modern plants are much reduced compared to old generation plants.

The workshop also allowed the identification of some factors of confusion that may affect the results of an epidemiological study and agreed on the variables that should be taken into account to evaluate the potential impact of an incineration plant, which we now mention to facilitate the re-evaluation of some previously presented works.

A confusing factor is the difficulty in translating the presence of hazardous substances into exposure information, except for those substances that can be biomonitored. It has often become necessary to estimate the exposure by factors such as the distance from the possible exposed to the source, which requires adjustments for example by the height of the column, the shape of the atmospheric dispersion plumes or the local wind rose at the time of the emission, factors that have not always been considered.

Another factor of confusion, sometimes critical, is the location of the plant and its vicinity to other probable sources of emissions or its establishment in neighborhoods with a shortage of basic services that make its population more vulnerable. The biggest challenge for these studies is how to eliminate the effects of confounding factors on the environment–health relationship, such as age, ethnicity, gender, socioeconomic conditions and access to health care, lifestyles, food quality and time of exposure.

In this scenario it should be noted that the emission conditions established by the European Union from the year 2000 define a before and after for the plants that motivated most of the known bibliography. Nevertheless, it is convenient to review some studies.

Epidemiological studies

Hu and Shy (2001) reviewed the bibliography for the period 1985–1999 by studying 11 publications evaluating the impact of incineration plants on the health of neighboring communities (in Australia, Scotland, USA, Finland, UK, Italy and Sweden) and 11 publications focused on plant workers. The various studies reported a wide variety of outcomes including associations with decreased proportion of male births, increased number of twins, increased number of cases of various types of cancer and blood levels of organic compounds and metals, while other studies showed the absence of changes in respiratory symptoms and lung function in some types of cancer. The authors concluded that the most striking feature of that review was that "the findings for cancer and reproductive outcomes were inconsistent"; that is, similar plants in comparable locations do not have comparable impacts, and emphasized the need to deepen epidemiological studies.

Rushton (2003) reviewed six studies carried out in the United Kingdom. Four of them reported cases of excess cancer (digestive system, liver, kidneys, pancreas and non-Hodgkin's lymphoma and for skin, stomach and respiratory system in occupational studies) and the possible association with low birthweight. The author concluded that:

> there is little evidence for an association with reproductive or developmental effects with proximity to incinerators. Studies of cancer incidence and mortality in populations around landfill sites or incinerators have been equivocal, with varying results for different cancer sites. Many of these studies lack good individual exposure information and data on potential confounders, such as socio-economic status. The inherent latency of diseases and migration of populations are often ignored.

Franchini et al. (2004) reviewed a total of 45 articles published between 1987 and 2003. Of these, 32 referred to the health of neighboring populations to incineration plants, 11 to occupational exposure and 2 included both situations. It was again stressed that in the vast majority of work the conditions of exposure were poorly described due to lack of information on emissions, the nature of the incinerated material and the migration routes of emissions, and they referred to first generation incinerators characterized by limited abatement technology and low combustion temperatures resulting in higher emissions. So it was difficult to compare the studies and consistency in the results would not be expected. Positive results were found for some specific types of cancer and inconsistent results for others, and inconclusive results for other non-tumor pathologies. Some conditions were also identified in occupational studies but not conclusive evidence, even with biomonitoring. The authors conclude that:

effect of biases and confounding factors must be considered in the explanation of findings. Methodological problems and insufficient exposure information generate difficulties on study results. Research needs include a better definition of exposure in qualitative and quantitative terms in particular by developing the use of biomarkers and by implementing environmental measurements.

A new review carried out by Defra in the United Kingdom (Enviros, 2004) "found no conclusive evidence of association between incinerators and cancer and reduced evidence of respiratory problems, stresses that in most cases emissions of incinerators make a minor contribution to local air pollution levels."

Cordier et al. (2004) studied the impact of the emission of the incinerators on the rate of congenital anomalies in the French region of Rhône-Alpes. This region has held a population register of these types of anomalies (register of the center-east of France) since 1978. Among the 2879 communities that exist in the region, they selected for the study the 2872 that have fewer than 50,000 inhabitants. Throughout the region, 70 incinerators were identified, which over the period of study (1988–1997) had been in operation for at least one year. They considered 194 communities to be exposed and 2678 not exposed. The study showed that the overall rate of malformations was not greater in the exposed areas than in the non-exposed (RR: 1.04; 95% CI: 0.97–1.11). An excess of risk was observed for some groups of anomalies: facial clefts and renal dysplasia. Although the associations found are biologically plausible, the same authors conclude that they must be very cautious in assessing them for the limitations presented by the study, mainly related to the way of estimating exposure, which makes it impossible to discard other explanations for the associations found. On the other hand, they point out that if there was any relation between the observed effects and the exposure to incinerators it should be attributed to the persistence of the pollution generated by old technology incinerators.

Other adverse effects studied include the prevalence of acute and chronic respiratory diseases, frequency of symptoms, hypersensitivity of the airways, atopy and indicators of respiratory function. Shy et al. (1995) from the University of North Carolina and USEPA studied simultaneously air quality and respiratory function and symptoms in three neighboring populations to incineration plants in the USA Residents were studied in an ellipse of 2 km × 5 km defining the major axis by the prevailing wind direction in each locality, and compared with three other locations without plants. Direct air quality measurements and estimates based on mass balances for a recipient model showed no impact on regularly monitored air pollutants. A baseline survey was also conducted ($n = 6963$, residents in 2592 households) that also did not reveal consistent differences between communities in the prevalence of both acute and chronic respiratory symptoms. A similar study was developed in Taiwan (Hu et al., 2001) in three areas neighboring incinerators and three control areas and studying 1018 individuals. The results found no significant differences between the populations exposed and those not exposed in terms of prevalence of respiratory illnesses or symptoms, adjusted by the use of gas stoves, the time of residence and the history of smokers.

Elliott et al. (1996) conducted a study in the UK which, after identifying what types of tumors could show increased incidence among residents in the environment of 20 incinerators, sought a confirmation of the findings obtained with the rest of the 52 operational WI in the country at that time. The analysis of the results showed that although in the first instance there was an increase in the expected cases of all combined cancers, stomach cancer, colorectal, lung and liver cancer, this effect was already observable in the period prior to the operation of such incinerators and before the minimum latency period considered for cancer in its entirety and for stomach, lung and colorectal cancer had elapsed, indicating that the observed effects were not attributable to incinerator emissions. The only type of cancer that showed a significant increase in the areas near the incinerators that was not randomly attributed was liver cancer. The authors point out that this effect is likely to result from the effect of socioeconomic variables associated with the urban environments closest to incinerators, as well as to the effect of poor classification of liver tumors. In a later study Elliot et al. (2000) showed an overestimation of the primary liver cancers in the total of the tumors for that location. Although this did not eliminate the increased risk found, it was significantly reduced. This result does not exclude the fact that the small increase observed was due to the confusion generated by socioeconomic factors. The findings of Elliott's studies refer in any case to "old" incineration plants, which were launched before 1976 and which are far from the characteristics of the current facilities that have to comply with EU legislation in emissions terms.

Porta et al. (2009) examined the published, peer-reviewed literature addressing health effects of waste management between 1983 and 2008, including 21 epidemiologic studies conducted on residents of communities with solid waste incinerators. They evaluated the overall evidence and graded the associated uncertainties. In most cases the evidence was inadequate to establish a relationship between a specific waste process and health effects; while the evidence from occupational studies was not sufficient to make an overall assessment. For community studies, at least for some processes, there was limited evidence of a causal relationship. For populations living within 3 km of old incinerators, there was limited evidence of an increased risk of cancer, with an estimated excess risk of 3.5%. The confidence in the evaluation and in the estimated excess risk tended to be higher for specific cancer forms such as non-Hodgkin's lymphoma and soft tissue sarcoma than for other cancers. According to the authors, the reviewed studies suffer from many limitations due to poor exposure assessment, ecological level of analysis and lack of information on relevant confounders.

Federico et al. (2010), from the Universitá degli Studi di Módena e Reggio Emilia (Italia), evaluated the incidence of cancer in residents of the city of Modena, neighbors within a radius of 5 km of the local WI plant. They reviewed the 16,443 new cases reported between 1991 and 2005. The space-time grouping identified three clusters but their formats could not be statistically associated with exposure to the plant, nor was any excess risk found in the area adjacent to it.

A deep review was presented by Mattiello et al. in 2013. Thirty-one papers on the health effects in the communities living in the proximity of incinerators were evaluated (2 cohort studies, 9 case–control studies, 17 ecological studies, 3 cross-sectional studies). The authors concluded that the evidence appears weak and conflicting in 15 studies, mostly ecological or case–control and only one based on a retrospective cohort, which analyzed the relationship between incinerator activity and cancer. Inconsistent results came from the evaluation of 10 studies (eight ecological, one case–control and one retrospective cohort study) analyzing birth defects and reproductive disorders.

Finally, it should be noted that at the beginning of the century a study was carried out in Japan to compare mortality rates, for all causes and five groups of major diseases, of 590 municipalities with WI plants with those of municipalities without WI plants (Fukuda et al., 2003). As indicators of exposure to dioxins, the concentrations of dioxin emissions from the incinerators were used, the amount of dioxins per population, the accumulated amount of dioxins and the amount of dioxins accumulated per unit of area. The results showed no significant differences for any of the causes of death analyzed when they were adjusted by the socioeconomic characteristics of the cities.

Risk assessment studies

In addition to the epidemiological studies identified, risk assessment studies have also been carried out. In these studies, different scenarios were established from available information on WI emissions, measurements of contaminants in environmental samples (air, soil, vegetables), eating habits, dioxin content of food and place of residence, among other factors. In each of the scenarios the doses of the different pollutants to which the population may be exposed and the different types of risk associated with this estimated exposure to WI plants were estimated in the USA (Hallenbeck et al., 1993; Nessel et al., 1991), Belgium (Nouwen et al., 2001), Spain (Schuhmacher et al., 2001) and France (Boudet et al., 1999), among others. The synthesis of the results indicates that, in general terms, neither direct exposure to emissions from the incineration plant nor indirect exposure due to food poses a significant additional risk of cancer for residents in the vicinity of the WI plant. In addition, the possible contribution of modern plant emissions to the levels of soil, flora and food contaminants generated in the plant environment does not appear to be significant, and given that the majority pattern of food consumption in urban areas has very varied provenance and only a small part comes from the same area, it is reasonable to consider that direct dioxin emissions from modern plants do not pose a significant risk.

Yoshida et al. (2000) assessed the health risk of dioxins in several population groups in Japan: general population, residents in the environment of a WI, high fish consumers and children and fetuses of all these groups, looking for adverse health effects such as cancer, reproductive dysfunctions, endometriosis and neurobehavioral effects. Although the estimated risks for cancer and reproductive dysfunction were not excessively high for the three defined adult groups, some doubts were raised about the risk of endometriosis, even when the evidence of causality in humans for this type of effect is very weak. In addition, the results suggested that children and fetuses of women living in the environment of an incinerator or major fish consumers may be exposed to a considerable risk of neuro-behavioral effects. These results have been taken with reservations because the data of the levels of contamination by dioxins (air, soil and vegetables) used in this study for the estimation of the daily intake in the population resident in the environment of the incinerators were, in general, far superior to those used in the risk assessments discussed above.

Biomarkers studies

As has been seen, in the studies of risk assessment the exposure to the various pollutants emitted by the WI plants is estimated from data obtained in the air, water, soils or other means, taking into account the different routes of exposure possible for each pollutant and making assumptions about the exchange of pollutants between the different environmental compartments. This external exposure may be considered only as a gross estimate of the dose of internal exposure to chemical components. In the studies with biomarkers, the concentration of the different compounds is measured in different organic compartments, which allows measurement of the internal exposure to which tissues and cells are subjected. In addition, some of these studies have had a longitudinal character, with follow-up over time for the same group of people with a before and after in relation to the start of the WI plant activity, which allows assessment of the impact that this activity has on internal exposure.

It is interesting to review the work done in Mataró (Barcelona, Spain), where the evolution of dioxin levels with time has been studied since the start-up of the municipal incinerator in 1995(these results can be considered as baseline levels) and was repeated in 1997, 1999 and 2002. The four evaluations compared the levels of dioxins in blood samples of the general population living in the vicinity of the plant (< 1.5 km) with the population that lives approximately 4 km from it. In 1999 and 2002 a third sampling was undertaken, incorporating a sample of a similar population located 20 km from the incinerator. The participants in the study were randomly selected from the municipal censuses. No significant differences were observed in dioxin levels among residents near and far from the incineration plant in any of the four evaluations performed. However, the studies showed a tendency to increase the levels of dioxins expressed in toxic equivalency (TEQ) from approximately 13 pg/g of lipid in 1995 to approximately 20 pg/g of lipid in 1999, consisting of all age groups and both sexes. In 2002, a decrease was observed in the presumably most exposed people (with a residence 0.5–1 km from the WI plant) and in the resident controls at 20 km, while in the control group of Mataró an increase was observed. The results suggested that changes in the level of dioxins observed could not be attributed to the WI plant, but should be related to dioxin levels in food (González et al. 1998, 2000, 2001; Unitat de Recerca, 2004).

In Germany, Deml et al. (1996) compared the concentrations of dioxins/furans measured in samples of blood and breast milk of people living in the environment of a WI, for more than 15 years, with concentrations found in the general population not exposed to known sources of dioxins. Both the blood and milk levels found were in the range of the background levels of the German population.

In Belgium, Fierens et al. (2003) studied the concentration of dioxins and polychlorinated biphenyls (PCBs) in blood of 84 subjects who had lived for an average of 18 years in the environment (within a radius of 2 km) of two old WI, which began to work in 1978 and 1980, one located in a rural area (51 subjects) and the other in an industrial area (33 subjects). These subjects were compared with 63 controls living in an uncontaminated rural area. Exposed people and controls regularly consumed locally produced foods. The people resident in the industrial environment did not have higher levels than the controls. However, residents in the WI environment located in the rural area showed in serum higher levels of dioxins than the controls. The difference in impact between the two WIs was attributed to the residents' dietary habits. According to the authors, the only determinants of the level of dioxins in the residents in the WI environment were the consumption of animal fat and age. The authors suggested that a significant increase in the level of dioxins is likely to occur only when dioxin emissions exceed 5 ng TEQ/m3.

In 2008, the National Institute for Public Health Surveillance in France, in collaboration with the French Food Safety Agency, announced the results of a national study on dioxin and PCBs levels carried out in 2005 (Fréry et al., 2008). Its main objective was to investigate whether the populations neighboring WI plants had different levels from those that lived far from them and to see to what extent the consumption of locally produced food contributed to that exposure. In a multicenter study more than 1000 adults (30–65 years old, average 52 years old, 54.7% women) residing in eight different locations were studied. The results showed that dioxin levels were similar to those reported in other European countries, with no significant differences between resident and non-resident populations in the area of impact of the WI. The only differences found were in the consumers of local animal products (including dairy and eggs) among residents in areas near old incinerators identified as polluters in the past. However, an increased risk of non-Hodgkin's lymphoma (NHL) was found among neighbors of a French municipal solid WI with previous high levels of dioxin emissions (Besançon, France) by using serum concentrations of pesticides, dioxins, furans and PCBs to assess exposure on 34 newly diagnosed NHL cases (2003–2005) and 34 controls. Authors were not able to present environmental levels of contaminants nor make it clear which source and route of exposure led to the pathogenesis of NHL in the study area (Viel et al., 2011).

Epidemiological studies were also carried out for two years after the operation of an incineration plant built in Bilbao, Spain, in 2005. Its results revealed that the blood and urinary levels of heavy metals (lead, chromium and mercury) in adults living in the environment were indistinguishable from those of more remote populations. Interestingly, cadmium levels were high but were not modified during the study period suggesting that the source of contamination was not the incineration plant (Begona Zubero et al., 2010).

Reis et al. (2007a) of the University of Lisbon carried out biomonitoring of the body load of dioxins, assessed by blood levels, of the general population living in the vicinity of a WI near Lisbon, which had operated since 1999, and on the island of Madeira, Portugal, operating since 2002. They concluded that the populations' exposure to the dioxins could not be related to the emissions from these facilities, which supports the effectiveness of the control of the sources of dioxin in both incinerators. The follow-up of a small group of people from Lisbon suggested the temporal effectiveness of the installation control there. As for the comparison between the levels of polychlorodibenzodioxins and polychlorodibenzofurans (PCDD/Fs) of the communities of Lisbon and Madeira, the individuals from Lisbon showed higher levels of PCDD/F, which can be better explained by the most highly contaminated areas of Lisbon than by eventual differences in dietary habits of the studied groups. The comparison between Lisbon and Madeira in relation to the pattern of congeners for PCDD/Fs showed a very similar profile. In the same study, stable and indistinguishable levels of total dioxin load controls were found in samples taken during 4 years of breast milk from mothers living in the vicinity of plants, and the already reported tendency for dioxin levels to increase with age (Reis et al., 2007b).

Other emissions

Bearing in mind that in the case of European plants these antecedents are limited by the normative changes of 2000 already stated we must revise some more recent antecedents.

For particles, mainly formed by ash, which can lead to heavy metals, acid gases, dioxins and furans, it is important to note that the usual methods of control of emissions in WI prevent the emission into the atmosphere of "breathable" particles (> 2.5 μm), but are limited for ultrafine particles (< 0.1 μm).

Heavy metals can be left in the residual ashes or evaporated, in which case they can be condensed when the gases are cooled, forming aerosols or adsorbed on the fly ash. It must be expected that ashes from WI deposited in landfills can contaminate the subsoil and groundwater with compounds that have leached from the waste; this has been documented. To avoid this, leaching should be reduced by stabilizing the fly ash with cement before depositing in safety fillers.

As previously mentioned, lead, cadmium, mercury, chromium, arsenic and beryllium are metals associated with WI emissions. All of them, in one or more forms, and by more than one pathway and route of exposure have been identified as responsible for a wide range of carcinogenic and non-carcinogenic effects on human health. However, in general, the epidemiological evidence of greater risk for environmental exposure levels in the WI environment is scarce or equivocal and it is therefore extremely difficult to assess the impact, if any, of the small exposure that incinerators could cause (Begona-Zubero et al., 2010; Lee et al., 2012; Ranzi et al., 2013; Reis et al., 2007a). In a study conducted in Shenzhen, south China, multiple exposure routes of heavy metals including Pb, Cr, Cd and Mn were assessed by investigating the metals in foods (such as vegetables, crops, meats and fruits), drinking water, ambient air and soil collected surrounding a WI facility. Vegetable ingestion played the most important role in the total average daily dose of Pb and Cr, and cereals were the key exposure routes for Mn and Cd (Li et al., 2017).

The emission of carcinogenic heavy metals that are part of the waste is preventable. In Germany, for example, it became compulsory in the mid-1990s to install filters (17th Ordinance on the Implementation of the Federal Immission Control Act—"17th BimSchV"), with significant results. Before 1990 toxic emissions were equivalent to 188 tonnes of arsenic. If we include in the calculation the emissions avoided when replacing fossil fuels by WI for the production of energy, in addition to that retained in the filters, we would be avoiding emitting another 3 t of arsenic per annum. The obligation to install filters for particulate matter had the same impact. The 25,000 t of particulates estimated to be released annually before 1990 fell by 2001 to less than 3000 t while another 5000 t were avoided from conventional fossil fuel-fired power plants, and in the emission of metals as mercury and lead.

The remaining critical group is that of organic compounds: polycyclic aromatic hydrocarbons (PAHs), dioxins and furans, products of incomplete combustion, which occur when the operating conditions are not adequate—low temperature, low oxygen level, insufficient time—or by plant overload, and can be detected by controlling the composition of the combustion gas.

Among them, particular importance is given to "dioxins and furans," due to their carcinogenic characteristics, and whose processes of formation and destruction have received great attention. Dioxins were first detected in municipal solid waste incinerator (MSWI) emissions in the 1970s in the Netherlands (Olie et al., 1977).

The polychlorodibenzodioxins (PCDD) and polychlorodibenzofurans (PCDF), especially 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), have generated enormous interest and concern in the population, mainly as a result of the accident that took place in 1976 in a chemical plant in Seveso (Italy). A large area around the plant was contaminated, initiating a whole series of investigations aimed at identifying the degree of environmental pollution and the health effects for residents according to their different levels of exposure.

The social impact of the term "dioxin" is fully justified by the high toxicity found in studies with experimental animals and the physicochemical characteristics of these substances, including their high chemical stability and liposolubility as well as their high resistance to metabolic degradation, which confers to this group of substances a great capacity for persistence and bioaccumulation. TCDD is classified as carcinogenic by the International Agency for Research in Cancer (IARC). Toxicological studies reveal a wide range of adverse effects: cancer, reproductive toxicity, immunosuppression, hepatotoxicity, neurological dysfunction, and dermatotoxicity.

However, epidemiological studies carried out with populations that have been accidentally exposed have not allowed confirmation of such a range of effects. Thus, although the discussion between different groups of researchers continues, and not all groups agree on the adverse effects that can be attributed to dioxins, it can be considered that there are different degrees of evidence in relation to different adverse effects. The effects for which a sufficient degree of association is established are: soft tissue sarcoma, non-Hodgkin's lymphoma and chloracne. Those for which the degree of evidence is considered to be limited or suggestive are: respiratory cancers, prostate cancer, multiple myeloma, spine bifida and acquired porphyries. Other adverse effects have been associated with weaker evidence. The cohorts that have been studied in more depth are those from the Seveso accident (1976) those from the Yusho (1968) and Yu-Cheng (1979) diseases in Taiwan, who were exposed through oil contaminated with a commercial mix of PCBs and dioxins, and the population of the Great Lakes environment in the U.S., exposed through ingestion of contaminated fish. Other cohorts, such as the American military personnel in contact with phenoxyacetic pesticides in Vietnam (1962–1970), and those affected by the transformer fire in Binghamton, New York (1981), have also served as an important source of information (Ansorena Miner, 2008, 2009; Ibarluzea and Basterretxea, 2004).

Evidence that inevitable dispersion of PCDD/Fs in the working environments during recycling and disposal of fly ash from MSWIs may pose health threats for onsite workers was recently demonstrated in southern Taiwan. Through assessing health risk with a Monte Carlo simulation, both the 95 percentile carcinogenic and non-carcinogenic risks for onsite workers exceeded the threshold limit (Hsieh et al., 2018).

The situation of the general population not exposed to occupational or accidental episodes cannot be considered similar to that described above. It is considered that the general population is exposed to dioxins mainly through the diet (> 90%). Exposure by air, air pollution and by dermal route is considered to be less than 10% (Reis et al., 2007a).

The gas purification systems currently used have minimized the possibility of releasing dioxins. According to the German Ministry of Environment, between 1990 and 2000 the emissions of the WI plants in Germany were reduced almost 1000 times and presently represent less than 1% of the emissions derived from human activity (Federal Ministry, 2005). In fact, the emissions of the WI plants are the source of dioxins that have been more drastically reduced: while in 1990 they were responsible for one-third of the total dioxins emitted, in 2000 they only accounted for 1% of emissions. Besides, it has been estimated that home chimneys discharge to the environment 20 times more dioxins than WI plants, an estimate supported by the seasonality of emissions that are five times higher in winter than in summer. Similar results were presented by the UK Ministry of Environment in 2004 (Enviros, 2004).

Studies carried out in the USA, France and Spain point in the same direction. In 2006 the Environmental Protection Agency of the United States of America (USEPA) published the inventory of sources and the environmental emissions of dioxins in the years 1987, 1995 and 2000, concluding that there was a 90% reduction in the emission of dioxins by WI in that period. Thus, the incinerators went from first to fourth place in the ranking of sources, with the burning of waste outdoors in first place (USEPA, 2006). All French MSWIs are operated well below the EU and French standard of 0.1 ng TEQ Nm3 (toxic equivalent nanograms per standard cubic meter) and their total dioxin/furan emissions decreased from 435 g TEQ in 1997 to only 1.2 g in 2008 (Nzihou et al., 2012). Several studies by AEVERSU (Spanish Association of Energetic Valorization of Urban Waste) carried out in the environment of several incinerators such as those of Reus, Mataró and Tarragona (all in Catalonia) or Zabalgarbi (in Bilbao) concluded that WI plants have no impact on their environment or on the health of people (AEVERSU, 2015; Rovira et al., 2015), and the Department of the Basque Government affirmed that "there is no scientific evidence that modern incineration and with limited emission levels suppose an additional risk significant for the health of the population." However, experience recommends the idea of continuous emissions monitoring (Universitat Rovira i Virgili, 2016).

A poorly studied aspect is the analysis of the environmental concentrations of volatile organic compounds (VOCs) and bioaerosols (fungi and bacteria) in the vicinity of a WI plant. A study carried out in Spain (Vilavert et al., 2009) found that these concentrations are very low, for example in comparison with the values inside and outside a composting plant or mechanical-biological treatment (MBT) plant and are at the lower level of the range found in the ambient air of various urban and industrial areas. Moreover, no correlation was found between these concentrations and the distance to the WI plant, although higher values were found in the prevailing direction of the wind and major—although statistically not significant—VOC values in the immediate environment of the incinerator, which the authors attribute to the greater accumulation of waste and the greater intensity of vehicular traffic in that area.

Almost 20 years ago Greenpeace evaluated WI in Austria to conclude that "The Austrian incineration plants have a high environmental standard as far as air and water emissions are concerned. Compared to other sources (industry, traffic, etc.) air and water emissions are relatively low" (Schuster, 1999).

More recently, the Health Protection Agency (2009) "reviewed the research carried out to examine possible relationships between the emissions of municipal WI plants and the health effects" to conclude:

> That while it is not possible to rule out with complete certainty possible adverse effects of modern and well-regulated plants of incineration on health, any potential harm to the health of those who live in their vicinity is likely to be very small, if it were detectable.

Moreover, Defra stated that "since any possible effect on health is probably very low or undetectable, it is not recommended to conduct public health studies in the environment of modern and well-managed incineration plants."

Some sectors of civil society have argued that living near as well as working in WI is associated with a wide range of health effects, including cancer (in adults and children), adverse impacts on the respiratory system, heart disease, effects on the immune system, increased allergies and congenital malformations. Holding this position, however, in most cases health effects that have been associated with the presence of incinerators have not been related to a particular contaminant (Allsopp et al., 2001; Carrasco-Gallegos, 2017).

Prevention more than precaution

In view of the possible consequences of poor management of the WI facilities and the difficulties enunciated to make any potential environmental damage evident, it is imperative to use a preventive strategy. It is noteworthy here that we speak of prevention and not of precaution understanding that in the case of "prevention," the danger of the thing or activity is already known and the only thing that is ignored is if the damage will occur in a specific case, while, in the case of "precaution," uncertainty rests on the very danger of the thing, because scientific knowledge is still insufficient to give a final answer about it. Thus, in the present case, we understand that "the first and most suitable is the prevention of damage to the environment, to avoid its completion". Especially given that it is a "non-monetized" good, that is, not translatable in compensation and difficult to return to the previous undamaged state.

Let us complement this conception by remembering that the precautionary principle applies when an activity is potentially threatening to the environment or human health even if the cause-effect relationships are not scientifically established, considering that definitive demonstrations are often not easy – because the conditions that science requires to establish causality are very demanding – and the delay in establishing precautionary criteria would allow the accumulation of damage.

None of these conditions is present in the proposal to operate a WI plant: the dangers associated with poor operation are known as well as the means to avoid them.

We understand that the implementation of a comprehensive environmental impact assessment, the establishment of a rigorous emissions standard, as the European Union has, and a rigorous emissions monitoring program that includes alarm signals, with public "on line" publication, appear as inescapable tools to ensure the prevention of the occurrence of environmental damage.

Adherence to this line of action would satisfy the obligation to carry out anticipatory activities required to prevent eventual damages, and to demonstrate the safety of the proposed process or activity, which are the full responsibility of the proposed development. They would also give the installation and operation process an open, informed and democratic character.

This direction, in the same sense, was already laid out in a number of international agreements: at the Stockholm Conference of 1972, which included it in recommendation No. 70 of the Plan of Action; in the Nairobi Declaration of 1982 which agreed that "Prevention of damage to the environment is preferable to the burdensome and extensive repair of damage already done" and in the Rio Declaration on Environment and Development of 1992, which contemplates externalities and applications of this preventive emphasis both in Principle 15 and in dealing with environmental impact assessment in Principle 17.

Within the wide range of measures to prevent environmental damage, the environmental impact assessment (EIA) is notable for its importance. EIA is present in the vast majority of national legal systems and unanimously recommended by international sources.

It should be recalled that the first country that incorporated the EIA in its regulations was the United States of America, through the National Environmental Policy Act (known as NEPA or U.S. NEPA), in 1969. Since then it has been consecrated in many national laws, including but not limited to: Germany (1971); Canada (1973); New Zealand (1974); Colombia (1974); Thailand (1975); Philippines, France, Venezuela and Ireland (1976); Australia (1979); Kuwait (1980); South Korea and Brazil (1981); Mexico, Indonesia and South Africa (1982); Pakistan (1983); the countries of Europe, following the pronouncement of the European Community through Directive 85/337/EEC of 27 June 1985 on "Assessment of the incidences of certain public and private projects on the environment"; and India and Guatemala (1986).

The implementation of preventive measures does not obey only to the fulfillment of the legal norms in force on the particular but also to a logical and unquestionable ethical reason.

Conclusions

Waste incineration has been a common practice in many countries since the 1960s and its technology has evolved over time, minimizing its emissions to neighboring communities. Data from Germany, the U.SA. and the UK reveal that the installation of suitable filters reduced the emission of heavy metals by 90% and dioxins by more than 99%.

For more than 50 years many studies have been carried out to establish the occurrence and magnitude of the risks that WI operation can mean for the health of the environment and of the people who live in the environment of the WI plants.

The vast majority of the works published until the first years of the 21st century referred to first generation incinerators characterized by limited technology of abatement and low combustion temperatures resulting in higher emissions.

The review of these works shows a general difficulty in circumventing the factors of confusion of the results. First, the difficulty in translating the presence of hazardous substances into exposure information, which has been often resolved by estimating the exposure by factors such as the distance from the possible exposed population to the source, without considering adjustments such as by column height, feather shape or local wind rose at the time of emission. Second, the vicinity of the plant to other probable sources of emissions. Third, the lack of tools to quantify the effects of other factors of confusion on the environment–health relationship, such as age, ethnicity, gender, socioeconomic conditions, access to health care, livelihoods, quality of feeding and exposure time.

The results presented by various epidemiological studies conducted in different countries (Australia, Scotland, USA, Finland, France, UK, Italy, Japan, Sweden) are inconsistent. They report a wide variety of outcomes (some report increased number of twins, increased number of cases of various types of cancer, increased blood levels of organic compounds and metals; other studies show no change in prevalence of acute and chronic respiratory diseases, in the frequency of symptoms, in hypersensitivity of the respiratory tract, in atopy, in indicators of respiratory function, in the number of congenital anomalies, in various types of cancers) but none of them is presented systematically.

Environmental epidemiology of WI suffers from limitations conducive to inadequate or contrasting results:

1. Because most disease are "rare" in populations, a large number of individuals have to be observed for a long time period to identify a potential determinant, and studies carried out in small communities for a limited number of years lack statistical power.
2. Specific attention is often given to communities where exposure is "visibly" higher compared with others, thereby emphasizing the effect.
3. Exposure is mostly not based on individual measurements or accurate modeling of differences in population groups.
4. Potential concomitant causes of harm to health should be measured and controlled for in the analyses as confounders such as the socioeconomic conditions.
5. There is a widespread lack of information on individual risk factors competitive for many diseases, such as smoking, dietary habits, alcohol use and occupation (Mattiello et al., 2013).

Risk assessment studies, which estimate the doses of the different pollutants to which the population may be exposed and the different types of risk associated with this estimated exposure in WI plants in Belgium, Spain, USA and France, show that neither direct exposure to plant emissions nor indirect food exposure poses a significant additional risk of cancer to residents in the vicinity of the WI plant, or for the natural resources of the installation environment.

In order to reduce the uncertainty many research groups have adopted studies using biomarkers that measure the concentration of the different compounds in different organic compartments, which allows identification of the internal exposure to which tissues and cells are subjected. In addition, some of these studies have had a longitudinal character, with follow-up over time of the same group of people with a before and after the start of the WI plant activity, which allows assessment of the impact that this activity has on the internal exposure. Studies conducted in Germany, Belgium, Spain, France and Portugal found no difference in dioxin levels among residents—in some locations for 15 or more years—in neighboring areas to incineration plants and the general population. The same results were found when the breast milk of mothers living in the vicinity of the plants was studied. Incinerator emissions make a minor contribution to local air pollution levels.

New assessments of the hypothetical sanitary impact of a WI plant will only come from epidemiological studies that include exposure routes and biomarkers and compare WI-related exposure with other sources of pollution.

The community perception of the risk associated with WI plants has a dual character that integrates individual and sociocultural factors, which in their interaction build the notion of risk of each individual. This notion is strongly tainted by its media visibility, beyond the specific probabilities that it will become an event, driven by "social cascades," informative – when the individual perception of risk is constituted through the perception of third parties, without independent sources of information that verify their veracity – and reputation – when the belief is based on social approval. As a result, the individual perception of risk and the likelihood of that risk being concrete for any individual do not have to agree.

A necessary condition for the development of a WI plant is to generate the conditions to prevent any impact that activates or potentially carries damage or risks to the environment and, in particular, to human health. Attentive to this, it is imperative to use a preventive strategy. The implementation of a comprehensive EIA, the establishment of an emissions standard and a rigorous emissions monitoring program appear as inescapable tools to ensure the prevention of the occurrence of environmental damage.

In summary, there is no known scientific evidence that WI plants designed and operated in order to comply with the emission standards in force in developed countries have a significative impact on the environment and the health of people living in their environment. Therefore, the establishment and compliance of emission standards should be sufficient to ensure their safety for the environment. The realization of a previous socio-environmental impact assessment and a participatory follow-up process of their operation are sufficient guarantees for the authorities and the community that the operation of the WI plant is a virtuous step in the management of waste with the added value of contributing to the reduction of greenhouse gas emissions.

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