Health risk assessment of municipal solid waste incineration

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Abstract

The incineration of municipal solid waste leads to the environmental release of some toxic substances, albeit of low atmospheric concentration in the proximity of the most recently built incinerators thanks to the substantial advancements in air pollution control equipment. An excess risk of some adverse health outcomes (cancer, birth defects, and respiratory diseases in particular) has been linked to the environmental release of these toxic substances on the basis of epidemiologic and laboratory studies.

The methodologies most frequently adopted by environmental scientists and regulatory agencies to evaluate these potential risk are the modelling of carcinogenic and non-carcinogenic health risks, and the implementation of epidemiologic studies in the populations residing near the incinerators. Geographic Information System (GIS) *software* to map specific diseases in the areas around the incinerators can also be used in support of data management and data representation.

We describe a health surveillance program concerning the population of a northern Italian town where the capacity of a municipal solid waste incinerator is planned to substantially increase in the near future. The program will analyse the risk of birth defects and spontaneous abortions in the population potentially exposed to the incinerator emissions.
Keywords: health, epidemiology, risk assessment, heavy metals, dioxins, geographical information system, incineration, municipal waste, reproductive health.

1 Introduction

The incineration of municipal solid waste raises important health problems associated with the toxicity of the stack emissions released into the environment as well as the problems related to combustion ash handling and disposal. In addition concern about these issues is prevalent in both the scientific community and public opinion (Domingo [1]; Snary, [2]; Rushton, [3]; Hamer, [4]; Franchini et al., [5]). These issues are therefore subject of increasing scientific interest and have received a particular attention from the regulatory agencies, as shown by the studies published on this topic and by the number of notes issued by the European Union and the US Environmental Protection Agency in very recent years. Nevertheless there are still uncertainties and conflicting results on the possible health effects of municipal waste incineration, and no consensus exists regarding the methodologies to be adopted as a means to assessing and monitoring these possible effects. In this paper, we briefly review the potential adverse health effects of municipal solid waste incineration and the methodologies which may be used in the assessment of health risks, including the approach that will be adopted to monitor these potential effects in a northern Italian community.

2 Potential health effects of municipal waste incineration

Incineration of municipal waste induces the environmental release of several contaminants, including organic and inorganic chemical compounds and biological agents, which might adversely affect human health through several pathways of exposure (Table 1). Furthermore, additional health risks may be generated through the handling and disposing of incineration ashes, due to the toxicity and the persistence of several combustion residues, which need to be carefully considered when assessing the health risk of municipal waste incineration.

Exposure to the contaminants emitted into the atmosphere during waste incineration may occur though the inhalation of polluted air, through ingestion of contaminated food and water and through dermal contact. Each of these pathways of exposure has specific characteristics and different risk patterns, which need to be considered during the assessment of health hazards related to waste incineration. Inhalation and dermal contact are generally more significant for the individuals residing in the proximity of the incinerators (taking into consideration the direction of the winds and the characteristics of the subjects exposed), whilst intake of contaminated food may affect exposure status in a considerably larger population.

Since the primary pollutants released into the environment by the incinerators are generally believed to consist of heavy metals and chlorinated organic substances such as dioxins, carcinogenic and reproductive risks are the main adverse effects, which have been hypothesized to be associated with waste incineration. In fact, a number of laboratory and human studies have shown that exposure to heavy metals such as chromium, cadmium, arsenic and nickel, as well as exposure to organic substance such as dioxins, furans, polychlorinated biphenyls and polycyclic aromatic hydrocarbons may increase the occurrence of genotoxic, immunologic and endocrine-disrupting effects, even at unexpectedly low concentrations (Franchini et al., [5]).

Apart from carcinogenic and reproductive effects, the possible occurrence of acute and chronic respiratory diseases and of neurodegenerative and neurobehavioural consequences has been suggested, but the limited number of epidemiologic studies so far published do not appear to support an increased risk of such outcomes in the exposed populations. Furthermore, the majority of the studies published on this topic examined populations exposed to the emissions of ‘old’ incinerators, in some cases selected after the detection of emission of unusually high amounts of contaminants, particularly of dioxins. Therefore, the results yielded by these epidemiologic studies may not apply to other populations exposed to the emissions of recently built incinerators, which were provided with considerably more effective devices for air pollution control.

Table 1: Health effects of pollutants emitted by waste incinerators.

Pollutants	Health effects
Particulate matter	Irritation of respiratory tract, increase of chronic obstructive pulmonary disease and worsening of asthmatic symptoms.
Acid gas emission Sulphur and nitrogen oxides, hydrogen sulfide, hydrochloric acid	Short and long-term respiratory effects, shortness of breath, irritation of eyes.
Heavy metals Lead, cadmium, mercury, arsenic, lead, nickel	Haematological and neurotoxic effects, increased risk of lung, kidney and bladder cancer.
Organic emission Dioxins and furans	Increased risk of cancer, birth defects, DNA damage, immune and reproductive effects.
Volatile organic compounds	Increased risk of cancer and nervous disorders, irritation of respiratory tract.
Polycyclic aromatic hydrocarbons	Mutagenic effects, increased risk of respiratory tract cancer.

3 Methodologies for risk assessment

Considerable efforts have been made in the most recent years to identify and improve effective methodology to assess the health risks associated with municipal waste incineration, particularly with exposure to incinerator emissions. Such growing interest has been supported by the scarcity of epidemiologic studies, the uncertainties regarding the health effects of low-level exposure to the pollutants emitted during waste combustion, the toxicity shown in laboratory studies by several of these contaminants, and the concern of most communities where the construction of new plants has been planned.

In general, two methodological approaches, alone or combined each other, have been suggested to assess the health risks of waste incineration: the calculation of exposure and toxicity models, and the implementation of epidemiologic studies and health surveillance programs. For both approaches a GIS (Geographic Information System) software can be used in support of data management and data representation.

3.1 The 'modelling' approach

Modelling 'theoretical' health risks has recently gained wide popularity in the most recent years in the scientific literature (Boudet et al., [6]; Domingo, [7]). This approach is based on the analysis of actual and/or predicted emissions of pollutants (mainly dioxins and related compounds and in some cases heavy metals) from the incinerators, the calculation of the intake of contaminants through the different routes (inhalation, ingestion and dermal absorption) and the assessment of the consequent carcinogenic and non-carcinogenic risks induced by such exposure on the basis of toxicological data from human animal studies. Such an approach is generally characterized by the rather low cost of implementation and its appreciable rapidity. It is, however, based on complex mathematical calculations and biological assumptions, and some of the assumptions required to implement these models are highly hypothetical, controversial and prone to substantial biases. Therefore, despite its benefits over other health risk assessment methodologies, the 'modelling' approach has gained limited popularity both in the public health community and in the general population.

3.2 The 'epidemiologic' approach

The 'epidemiologic approach', if not somewhat surprisingly, has rarely been used to assess the health risks of municipal waste incineration, even if epidemiology is the basis for any kind of risk assessment in a public health perspective, and concern for the health effects of waste incineration is widely spread throughout different countries and communities all over the world (Franchini et al., [5]). Both ecologic and individually-based studies may be used to test the health effects of an incineration plant, although the latter investigations, in the form of cross-sectional, case-referent and cohort studies, are as usual the most appropriate to identify the health effects of the source of contamination. Unfortunately, yet justifiably, nearly all of the limited number of studies so far published were designed to assess the long-term effects of incinerators emitting high amounts of dioxins or related compounds. In the most recent periods, however, the design of long-term epidemiologic studies on the health effects of 'new' incinerators, i.e. the implementation of surveillance programs, is now being taken into serious consideration (Anonymous, [8]). One of the critical issue regarding epidemiologic studies that actually examine the health effects of waste incineration is the suitability of outcomes under examination to precociously indicate the health risks associated with incinerators emissions exposure. Cancer incidence, for example, is clearly inadequate to monitor the occurrence of adverse health effects of 'new' municipal waste incinerators, as a lengthy time period may be required to induce and identify epidemiologically detectable excesses of risk. In fact, when following a 'low-dose' exposure, some decades may be necessary to induce in the exposed individuals a clinically evident disease. This means that several years are needed to detect possible increases in cancer risk associated with incinerator emissions, and even in such cases it is likely that on observation of the effects, the technology controlling incinerator stack air emissions will have already been updated. Acute diseases such as respiratory infectious disease are also inadequate to be included in epidemiologic studies and health surveillance programs, since the amounts of pollutants inducing respiratory disease released by the incinerator stack into the environment are very limited, particularly if compared with the other sources of pollution. This, more than likely, explains why most studies concerning the effects of incinerators emissions on respiratory health have been unable to find any relation. An end-point which may be adequate in assessing health risks associated with waste incineration is the evaluation in the potentially exposed populations of reproductive health outcomes, such as the risk of having a child with a birth defects, of still-birth and of spontaneous abortion. In this case, the end-point adopted would allow for the quick detection of any possible excess risk in the exposed populations, i.e. within a few months from initial exposure. Furthermore, the mechanisms of toxicity involved in the above-mentioned reproductive health failure are probably, to a certain extent, similar to those involved in the process of cancer causation, suggesting that reproductive health outcomes might be used as a surrogate indicator of future cancer risk.

3.3 The Geographical Information System

A Geographic Information System (GIS) can be defined as a powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough and McDonnell, [9]). The geographical (or spatial) data represent phenomena from the real world in terms of (a) their position with respect to a known cartographic or geographic coordinate system, (b) their attributes that are un-related to position (such as pollutant concentrations and incidence of diseases), (c) their spatial interrelations with each other which describe how there are linked together (topology).

GIS have three important components: computer hardware, a set of application software modules, and a proper organizational context including skilled people. In particular, GIS software may be split into four functional groups: data input and verification; data storage and database management; data output and presentation; interaction with the user.

GIS use requires the organization of the work inside a project. The first step of this project is the choice of the spatial domain (studied area) and of the geographic or cartographic coordinate system to be used to refer spatial location of input data and results. The definition and organization of the other steps can not be described in a few phrases; to summarize, it can be said that there are three main phases: data input, data elaboration, presentation of the results. Data organization, elaboration and presentation are based on the concepts of feature and of layer. A feature is a representation of a real world object, such as the spatial concentration of a pollutant or the street of a city, in a layer (Longley et al., [10]). A layer is collection of similar geographic feature, such as spatial concentration of different pollutants, streets and buildings of a city, of a particular area or place for displaying on a map. Features data are structured in two main data format: raster and vector. In the raster format a grid structure to store geographic information is used. In the vector format geographic information is associated to geographic features as points, lines and polygons.

4 Methodology for health risk assessment of a new incinerator: a case report

In 2004, the Modena Municipality Agency in charge of Waste Collection and Disposal (named META) was authorized by the local Authorities (the Province and the Municipality) to considerably increase the capacity of the local municipal solid waste incinerator. The capacity is now planned to double from 120.000 tons/year to 240.000 tons/year in 2007, and this will be achieved by building two additional 'lines' (i.e., two more combustions chambers). However, in order to authorise the increase in the incineration capacity META was invited to monitor the potential health risks associated with such development, implementing a surveillance program for the potentially exposed population. Here we present the design of such a public health surveillance program about to commence its activity.

The program will focus on one of the main effects associated with exposure to incinerators emissions, the adverse effects on reproductive health. In particular, an analysis of the areas where the highest amounts of contaminants will be released into the atmosphere will be carried out, in order to identify two areas, defined as intermediate-exposure and highest-exposure areas, where population intake of the pollutants emitted by the incinerator is expected to be higher than in the remaining municipal territory (Figure 1). To do this, we used the ISC3 (Industrial Source Complex version 3) model (USEPA, [11]), in order to predict the atmospheric concentrations of two groups of pollutants (dioxins and heavy metals) which should occur at 0-2 m of height in the vicinity of the incinerator.

In the populations residing in the two exposed areas and in a referent region, represented by the remaining municipal territory of Modena, we will attempt to identify all the spontaneous abortions, the induced abortions associated with birth defects, the live-births and the still-births with and without the occurrence of congenital anomalies occurring during the study period (2003-2011), aiming at detecting possible changes in the incidence of both reproductive effects and more general chronic diseases in the exposed population. To do this, we will review the hospital discharges and birth certificates related to the above-mentioned reproductive outcomes in all the females residing in the Modena municipality. This analysis will include both the 4-years period prior to the

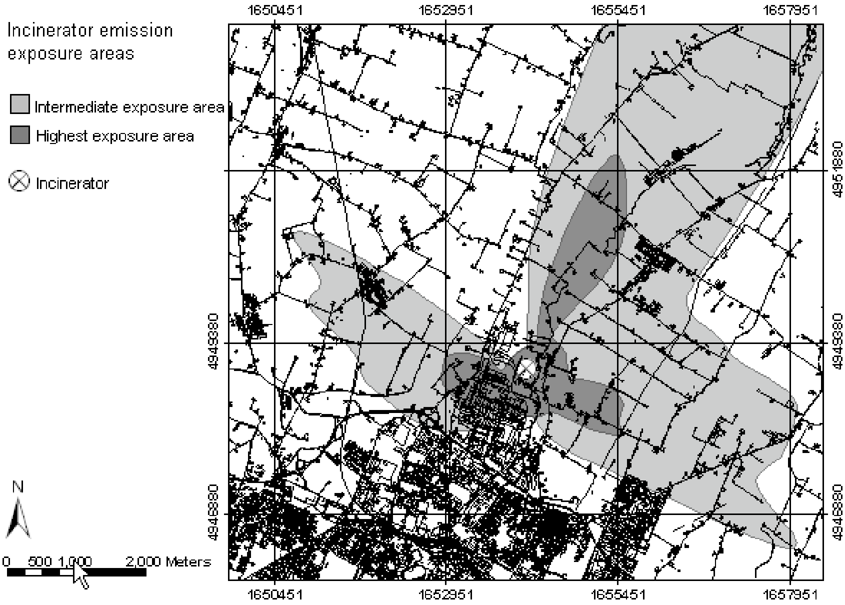

Figure 1: Map of exposure to Modena municipality waste incinerator emissions.

start-up of the facility, when a smaller incinerator will continue to operate, and the subsequent 5-years period in which the new plant will be operating. The data collected by the Emilia-Romagna Congenital Malformations Registry (operating within the European Union EUROCAT program) will also be reviewed. Analysis of these data will allow for the calculation of the relative risk of having a child with a birth defect or a spontaneous abortion associated with maternal residence in the high- and medium-exposure areas, and with maternal employment in one of the factories located in the two exposed areas, for each one-year period from 2003 until 2011. We will also take into consideration factors such as place of birth, ethnic group, gestational age, type of occupation and socioeconomic status, to reduce the risk of confounding, by using a multivariate unconditional logistic regression model. Finally, we are constructing a GIS project on the studied area using the software ArcGIS™. At the moment, several features have been loaded in the layers of the project and others will be loaded, or generated by data elaboration, during the ensuing phases of the study. Data location are referred to on the standard Italian cartographic system (Gauss-Boaga projection, Datum Roma40). Among the most important features considered there are:

- The Regional Technical Map of Modena Municipality (Comune di Modena, [12]) at the 1:10000 scale in vector format. This technical map contains a great deal of urban information on streets, buildings, railroad, water bodies and parks.
- The aerial photograph of the area at 1m x 1m of spatial resolution (about 1:2000 cartographic scale). This feature, in raster format, is useful to have a faithful visual representation of real world;

- The spatial distribution of the concentration of several aerial pollutants simulated by ISC3. This model gives concentration estimations for each points defined on a regular spatial grid. Presently, the dispersion of PM10, dioxins, and heavy metals have been considered.
- Demographic data. This information has been organized in georeferenced tabular data and inserted in the layers as vector (points) features.

The considered features form a geographic database that represents the basic datasets used by ArcGIS™ software in support of the epidemiological study. In particular it is possible: a) to obtain a spatial representation of the parameters needed for the epidemiological analysis; b) to make elaborations (statistic, logic, arithmetic, etc.) of the spatial data; c) to represent the results in different, powerful ways, such as overlay on cartographic maps, diagrams, isolines, colours scale and text reports.

5 Conclusions

Conflicting results have been published on the possible relation between waste incineration and adverse health effects. Overall, the considerable reduction of the emissions achieved by the air pollution control devices adopted in the most recently built incinerators and the evidence provided by the few epidemiologic studies carried out on the health effects of the ‘old’ plants suggest that residence near modern municipal waste incinerators is unlikely to be associated with relevant adverse health effects, particularly with excess risk of cancer and respiratory disease. However, the scientific uncertainties still existing on this issue and the growing concern in the ‘exposed’ communities provide the opportunity to implement health surveillance programs in such populations. We propose that such surveillance should focus on short-term toxicological endpoints such as reproductive health outcomes, which may also act as indicators for excess risks of chronic-degenerative diseases.

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