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Aspergillus fumigatus and mesophilic moulds in air in the surrounding environment downwind of non-hazardous waste landfill sites

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ABSTRACT

Non-hazardous waste landfilling has the potential to release biological agents into the air, notably mould spores. Some species, such as *Aspergillus fumigatus*, may be a cause of concern for at-risk nearby residents. However, air concentration in the surrounding environment of non-hazardous waste landfill sites is poorly documented. An extensive sampling programme was designed to investigate the relationship between culturable mesophilic moulds and *A. fumigatus* concentrations in air and distance downwind of non-hazardous waste landfill sites. On-site and off-site repeated measurements were performed at four landfill sites during cold and warm seasons. A high-flow air-sampler device was selected so as to allow peak concentration measurement. Linear mixed-effects models were used to explain variability in the concentrations in air over time and across sites, seasons, instantaneous meteorological conditions and discharged waste tonnage. Concentrations of mesophilic moulds and *A. fumigatus* at off-site upwind sampling locations were compared with concentrations at each of the downwind sampling locations.

At the tipping face location, peak concentration reached 480,000 CFU m^{-3} for mesophilic moulds and 9300 CFU m^{-3} for *A. fumigatus*. Compared with upwind background levels, these concentrations were, on average, approximately 20 and 40 times higher respectively. A steep decline in the concentration of both mesophilic moulds and *A. fumigatus* was observed between the tipping face location and the downwind property boundary (reduction by 77% and 84% respectively), followed by a low decline leading to a 90% and 94% reduction in concentration at 200 m from the property boundary and beyond. With the 200 m and 500 m downwind sampling point values added together, the 97.5th percentile of concentration was 6013 CFU m^{-3} and 87 CFU m^{-3} for mesophilic moulds and *A. fumigatus*, respectively. Other determining factors were the discharged waste tonnage, the season, instantaneous temperature and wind velocity for mesophilic mould, and instantaneous temperature for *A. fumigatus*. At 200 m and 500 downwind from the property boundary, mesophilic moulds and *A. fumigatus* concentrations were still higher than the local background level. However, whilst statistically significant, this increase does not suggest an excess risk to nearby residents' health when compared with the wide range of outdoor background levels reported in literature.

These findings suggest that moulds and *A. fumigatus* may be transported beyond 200 m from the property boundary in concentrations above those found locally upwind of the landfill site. Nevertheless, for exposure assessment purposes, comparison should also be made with background levels in wider areas which are either residential or through which people travel to work for example.

1. Introduction

The 1999 European Landfill Directive (Council Directive 1999/31/EC) motivates to redirect biodegradable municipal waste from landfill towards alternative treatments that ensure recycling and energy recovery from organic waste. Furthermore, environmental protection stakes have progressively led to an increase in the cost of non-hazardous waste landfill site operation. Subsequently, in France, the number of operational non-hazardous landfill sites has decreased from more than 500 in 1992 to 238 sites in 2012 (Ademe, 2012a). However, despite advances in recycling and recovery technologies, the landfilling of final waste cannot be avoided and landfill sites are still required for waste management (Ministère de l'écologie, du développement durable et de l'énergie, 2015). In 2012, about 19.5 million tonnes of non-hazardous waste was discharged into landfills, representing 38% of the total tonnage

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(Ademe, 2012a). Residual household waste and commercial and industrial waste together accounted for 61% of total non-hazardous waste discharged into landfill sites.

Modern landfills are well-engineered facilities that are located, designed, operated and monitored to protect the environment and public health from contaminants which may be present in waste streams (U.S. Environment Protection Agency, 2014). Briefly, non-hazardous waste originating from households and enterprises arriving at a landfill site is weighed and the truck content is checked by operators to ensure it complies with the landfill operating licence. Then, the trucks unload the waste at the tipping face, which can be an unloading dock. The tipping face is the operational area of the landfill site. Discharged waste is then compacted by mechanical equipment and regularly covered with layers of soil or inert materials in order to reduce odours and control litter, insects, birds and rodents. The decomposition of waste by micro-organisms, combined with rainwater filtering through the landfill, results in the production of leachate and biogas. The waste is stored in leak-tight compartments divided into cells, the bottom and sides of which are lined with natural materials and composite liners. Leachate contained by the lining system is collected by a network of drains and deposited into storage tanks. It is then either taken off-site to be treated, or pumped into an on-site treatment plant. Biogas is captured through collection pipes, burned off in landfill flares or is directed to an on-site energy generation plant. When a cell is completely filled, it is covered by a final leak-tight layer and vegetation.

The operation or the project to extend a non-hazardous waste landfill site often raises concern and/or opposition from neighbouring populations, and health issues have emerged and have served to strengthen their arguments (Eyles et al., 1993; Giusti, 2009; Maresca et al., 2012; Rahardyan et al., 2004; Rasmussen, 1992). Potential health issues related to water pollution are identified and regulated through shared standards, and the site manager is expected to implement technical solutions that will control potential waterborne health risk. Regarding air pollution, the site manager faces the challenge of having to provide evidence that operating a non-hazardous waste landfill is a low risk activity. However, arguments relating to this issue are still in their infancy (Maresca et al., 2012). Most published studies on air pollution generated by landfill sites have focused on chemical hazards resulting from the disposal of hazardous waste and the co-disposal of non-hazardous and hazardous waste (Almaguer and Martinez, 1996; ATSDR, 1998; Esswein and Tubbs, 1994; Giusti, 2009; Institut de Veille Sanitaire, 2004; Kirivanta et al., 1999; Rahkonen et al., 1987). However, non-hazardous waste landfilling also has the potential to release biological agents into the air, i.e., bioaerosols.

Bioaerosols consist of live and dead micro-organisms, as individual micro-organisms or as aggregates, fragments and products of micro-organisms such as bacterial endotoxins, glucans and mycotoxins, and any of the above carried on other particles (ACGIH, 1999). The interest of scientists and health authorities in bioaerosol exposure has been increasing for a few decades, primarily because of the association between exposure to biological agents in occupational and residential environment and a wide range of adverse health effects including infections, immuno-allergic outcomes, and toxic effects (ACGIH, 1999; Douwes et al., 2003; Dutkiewicz, 1997; Swan et al., 2003). Several studies have investigated exposure levels to bioaerosols in the organic waste management field. Most focussed on workers' exposure, particularly in composting facilities (as reviewed by Ademe, 2012b; Pearson et al., 2015; Swan et al., 2003). Regarding emissions and dispersal of bioaerosol from waste processes, data is limited and also focussed on the topic of commercial composting facilities (Fischer et al., 2008; Le Goff et al., 2012; O'Connor et al., 2015; Pankhurst et al., 2011; Taha et al., 2006). In the field of non-hazardous waste landfill operations, this issue is currently poorly documented. Waste materials present in landfill sites contain micro-organisms from incoming biodegradable waste, and from the growth of bacteria and fungi favoured by humidity and temperature (Miller and Clesceri, 2002; Pahren, 1987). Bioaerosols are mainly released when waste collection vehicles transport and unload their contents, when bulldozers spread and level the waste on the working face, and when waste layers and their coverings are compacted by mechanical equipment. Biogas leaks and leachate treatment constitute other on-site sources of biological agent emission.

In organic waste, the main microbial populations are bacteria and fungi (Miller and Clesceri, 2002; Pahren, 1987; Palmisano and Barlaz, 1996). In the case of fungi, owing to the decomposition of stored organic matter, storage moulds such as *Aspergillus* and *Penicillium* predominate at municipal solid waste landfill sites (Hours and Berny, 2001; Krikstaponis et al., 2001; Obire et al., 2002; Reinthaler et al., 1999). This differs from the usual polymorph fungi populations present in outdoor air, where mesophilic moulds, such as *Cladosporium*, *Alternaria* and *Didymella*, which develop on grass and other living plants, are most prevalent (Dutkiewicz, 1997). Furthermore, *Aspergillus fumigatus* readily grows on damp building materials (gypsum board, wood, chipboard, cardboard and mineral wool) that can be discharged into non-hazardous waste landfills as commercial and industrial waste (Nieminen et al., 2002). Due to the small size (2–3 μm) and the hydrophobicity of its spores, their resistance to UV radiation and temperature, and their low settling rate, *A. fumigatus* remains airborne for very long periods and is quite well-suited to air dispersal (O'Gorman, 2011; Rhodes, 2006).

Most moulds are not harmful to humans. However, certain species can cause airway and lung disease by acting as an aeroallergen or as an infectious pathogen, and in the case of some species, by both mechanisms (Denning et al., 2014; Knutsen et al., 2012; Latgé, 1999; Woolnough et al., 2015). It is noteworthy that, as recently concluded by a bioaerosol expert network, the studies which are currently available do not provide suitable dose-response relationships which can be applied to set health-based exposure limits for long-term exposure to bioaerosols (Walser et al., 2015). This conclusion is obviously valid for fungi.

As emphasised in a recent position paper published by the European Academy of Allergy and Clinical Immunology Asthma Section, "*A. fumigatus* is remarkable as it can cause invasive infection in the immunocompromised, chronic pulmonary aspergillosis and *Aspergillus* bronchitis in non-immunocompromised individuals with underlying lung damage, and allergic disease of the upper and lower airways" (Denning et al., 2014). Consequently, pulmonary disorders linked to *A. fumigatus* can be regarded as health outcomes that occur along a semi-continuous spectrum of diseases, mainly based on the immune status of patients and on pre-existing lung damage (Cornillet et al., 2006; Denning, 1998; Gefter, 1992; Kosmidis and Denning, 2015; Latgé, 1999; Lortholary et al., 2013; Woolnough et al., 2015). The main underlying conditions of invasive aspergillosis are acute leukaemia, allogeneic stem cell transplantation, chronic lymphoproliferative disorders, solid organ transplantation, solid tumours, inflammatory diseases and chronic respiratory diseases (Cornillet et al., 2006; Denning, 1998; Latgé, 1999; Lortholary et al., 2013). At the other end of the spectrum, allergic bronchopulmonary aspergillosis (ABPA), which affects patients with asthma or cystic fibrosis, constitutes the principal clinical disorder due to *Aspergillus* hypersensitivity (Chaudhary and Marr, 2011; Denning et al., 2013; Gefter, 1992; Knutsen and Slavin, 2011). In addition, sensitisation to *A. fumigatus* has also been associated with reduced lung function in severe asthma (Denning et al., 2014; Fairs et al., 2010; Menzies et al., 2011) and chronic obstructive pulmonary disease patients (Bafadhel et al., 2014). The burden of allergic fungal airway disease is important. In a scoping review, Denning et al. (2013) estimated that the prevalence of ABPA in adults with asthma was 2.5%, whilst modelling