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Typical benign indoor aerosol concentrations in public spaces and designing biosensors for pathogen detection: A review

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ABSTRACT

The use of biological agents against enemies has persisted throughout centuries and the use of Anthrax spores on civilians in USA in 2001, suggests a growing worldwide threat. Safeguarding spaces under attack requires rapid detection and identification. *Bio-protect* is a project supported by the European Commission, with the concept of developing a fast-alert, mobile, easy-to-use device to detect and identify airborne pathogens. It is important that biosensors are both selective and sensitive as interference with or response to benign indoor aerosols in their typical concentrations can create panic. The purpose of this paper is to provide background information on typical levels of benign indoor aerosols.

We performed a literature search to identify relevant original studies reporting indoor aerosol concentrations in areas we considered could be targeted by malicious attacks of bioterrorism including assembly spaces as well as the transport sector.

We identified 95 eligible studies representing different seasons and geographical and climatic regions. Levels of indoor aerosols ranged over several orders of magnitude and were mostly affected by indoor human activities and population density, outdoor air levels and ventilation type. Outdoor variables most important for non-bioaerosols were proximity to major roads and composition of the vehicle fleet, whilst for bioaerosols season and geography were the most important.

Selectivity and sensitivity issues are very important in designing and manufacturing biosensors. The ranges of the typical indoor aerosols presented in this study can be used as a reference in designing biosensors used for improvement of public security.

1. Introduction

The use of biological agents as a means of defeating enemies has persisted throughout centuries and following the scientific breakthrough of Koch in understanding the germ theory in the late 19th century, bioweapons found increasing emphasis [1–3]. The Geneva Protocol of the League of Nations in 1925 prohibited the use of chemical and biological weapons in warfare but the Protocol did not prohibit their development or stockpiling [4]. The most notable development in bioweapons control since then has been the Biological Weapons Convention (BWC) of 10 April 1972 [5], which was enforced on 26 March 1975. The BWC prohibited development, production and stockpiling of biological and toxin weapons and mandated their destruction. A total of 162 nations signed the BWC, however the weakness of BWC was the lack of provisions for on-site inspection and verification [6].

Information and technology for bioterrorism is ubiquitous and easily obtainable in non-classified scientific journals and on the internet. The use of Anthrax spores on civilians in USA in 2001 [7], suggests that these bio-agents are becoming an increasing threat to the whole world community, including Europe. There is now a common awareness of the necessity to include this threat in emergency and risk management plans in the European Union so normal citizens are protected from bioterrorism. High-priority bio-agents can be defined as being easily disseminated or transmitted from person to person with high morbidity and mortality rates, difficult diagnosis, creation of public panic and social disruption as well as major public health impact potential. Compared to conventional weapons, relatively small amounts of biological agents

Abbreviations: ACH, air changes per hour; BWC, biological weapons convention; PM_{10}, particulate matter with diameter <10 μm; $PM_{3.5}$, particulate matter with diameter <3.5 μm; $PM_{2.5}$, particulate matter with diameter <2.5 μm; PM_1, particulate matter with diameter <1.0 μm; UFP, ultrafine particles; CFU, colony forming units.

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may cause high numbers of casualties. The Centers for Disease Control and Prevention has a compiled a list of the 12 most common high-priority bio-agents (Table 1), these range from bacteria such as *Bacillus anthracis* (the causative agent of anthrax) to viruses such as *Variola* (the causative agent of smallpox) and *Ebola* [8].

Safeguarding a certain space under attack requires rapid detection and identification techniques. *Bio-protect* is a project, supported by the European Commission under the seventh Framework Programme and the concept of *Bio-protect* is the development of a fast-alert, mobile, easy-to-use device to be applied in detection and identification of airborne pathogenic bacteria, spores, viruses and toxins. The technology of the device will be described in detail elsewhere, but in brief it is based on bio-aerosol detection by fluorescence, scattering and background aerosol measurement followed by ionization of air flow and analysis of the spectrum of relative speed of passage, which, in turns, enables identification of harmful biological agents. Besides being fast, mobile, user-friendly and inexpensive it is important that biosensors are selective and sensitive. Biosensors should not respond to benign indoor aerosols in their typical concentrations, as false positives or negatives can have serious consequences. In this context, benign indoor aerosols are considered not acutely toxic or lethal, but often found indoors. The indoor concentration of these benign aerosols can in some situations exceed the desired detection concentration of the hazardous biological agent challenging biosensor sensitivity, and structural similarities between benign and pathogenic aerosols challenge the selectivity of biosensors. Values for generally acceptable indoor aerosols vary from country to country and are summarized in Table 2, however, these values are primarily based on health effects and don't reflect actual aerosol profiles found indoors. It is important that designers, scientists and BETA testers are aware of typical concentrations of benign aerosols and there is an acute need for a collection of reference values of typical levels indoors. This review is a part of the *bio-protect* project with the purpose of providing reference levels of typical benign indoor aerosols.

2. Material and methods

We performed a literature search to identify studies reporting indoor concentrations of aerosols in areas we considered could be targeted by malicious attacks of bioterrorism: assembly spaces (universities, offices, libraries, museums, hospital, schools, airport terminals, restaurants and underground stations), as well as the transport sector (buses, taxis, trains and planes). We excluded papers which were not published in English, did not include original data, did not utilize active sampling of aerosols or only presented results graphically. Studies only reporting levels within smoking and mold complaint spaces were not considered eligible. A comprehensive search for relevant papers in several databases was conducted incl. SCOPUS; Science Direct; EMBASE and Ovid MEDLINE. The search was limited to the last 14 years (1 Jan 2000 to 1 Jan 2014), to give the most recent update of aerosol levels. In addition to searching databases we searched the reference lists of eligible studies and relevant reviews, as well as the web search engine "Google" for additional published studies. We used keywords related to indoor aerosols [indoor air quality, bioaerosols, fungi, pollen, molds, PM, indoor environment] in combination with [university], [hospital], [library], [museum], [school], [office], [airport], [bus], [train], [plane] or [subway or metro or train station or railway station].

We identified 176 papers in the period January 2000 and January 2014 and of these 95 were eligible. These studies represented different regions and climatic conditions worldwide including 19 countries in, 1 state in Australia, 11 states in USA, 2 provinces in Canada, 7 countries in Asia, as well as 1 country from each of the following continents/regions: Africa, central America and the Middle East. Eleven studies considered aerosol concentrations according to season.

Table 1
Classification of the "Dirty Dozen" – high priority bio-agents and their disease.[a]

Group, causative agent	Disease	
Bacteria		
Bacillus anthracis	Anthrax	A[b]
Yersinia pestis	Plague	A
Francisella tularensis	Tularemia	A
Brucella spp.	Brucellosis	B
Burkholderia pseudomallei	Melioidosis	B
Parasites		
Coxiella burnetii	Q fever	B
Viruses		
Variola major	Smallpox	A
VEE virus	Venezuelan equine encephalitis	B
Filo viruses (e.g. Marburg, Ebola)	Viral hemorrhagic fevers	A
Toxins		
Clostridium botulinum toxin	Botulism	A
Ricin	Ricin poisoning	B
Staphylococcal enterotoxin B (SEB)	SEB poisoning	B

[a] Adapted from Center of Disease Control.
[b] Category A: high-priority agents pose a risk to national security, can be easily transmitted and disseminated, result in high mortality, have potential major public health impact, may cause public panic, or require special action for public health preparedness; Category B: moderately easy to disseminate, with moderate morbidity and low mortality rates [8].

Table 2
Guideline values for indoor aerosols.

Country/Organization	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	Viable molds (CFU/m^3)	Viable bacteria (CFU/m^3)
Brazil [81,82]			750	
Belgium	40 (24-h)	15 (1-y)		
Canada [83]		40 (1-h)	150[a]	
China	180 (8-h)	150 (24-h)		2500–7000[b]
Finland [84]				4500
Germany [85]			1000	1000
Korea [53]				800
Netherlands [86]				10000
Norway		20 (4-h)		
Portugal [87]			500	
Russia [88]			2000–10000[c]	
Switzerland [89,90]			1000	10000[d]/1000[e]
Taiwan	150 (24-h)	100 (24-h)		
USA [91]	150 (24-h)	65 (24-h)	1000	
WHO [92]				500
European Union [93,94]			10000[f]/2000[g]	10000[f]/2000[g]

[a] For a mixture of species.
[b] Depending on locations such as hotels, movie theatres, libraries and museums.
[c] Depending on the fungal species.
[d] For aerobic Mesophilic bacteria.
[e] For Gram-negative bacteria.
[f] For private homes.
[g] For Non-industrial indoor locations.

3. Results

Indoor spaces in *underground subway stations/airports* (Table 3); *in-transit* (Table 4); *food venues and public buildings* (Table 5) as well as *schools and universities* (Table 6) are all represented. Levels of indoor aerosols were reported to be influenced by indoor human activities, population density indoors, outdoor air levels and ventilation type. Outdoor variables most important for non-bioaerosols were proximity to major roads and composition of the vehicle fleet, whilst for bioaerosols season and geography were the most important. A summary of average levels reported according to