Analytical Equations Relating Aerosol Risk to Surface Concentrations

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Background

After the 2001 anthrax attacks, there is a need to relate environmental concentrations of *B. anthracis* to human health risk. This may inform decisions to initiate treatment of individuals potentially exposed to *B. anthracis* or to reopen a contaminated building after cleaning. Much of the human health risk is associated with aerosol exposures, but air concentrations would rapidly decay after a release. In this situation environmental samples taken from surfaces and HVAC filters are related to both past and future aerosol risks.

Model Introduction

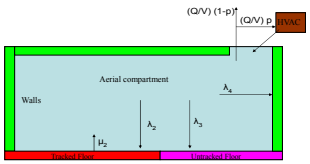

Figure 1. Schematic of model

We consider a simple office suite with an HVAC system as in Figure 1. We partition the office into 5 internal compartments

(i) Aerial compartment.

(ii) Tracked floor which is walked upon.

(iii) Untracked floor.

(iv) Walls.

(v) HVAC filter.

Using the mass balance relationships in our office suit we can obtain the following system of linear first order differential equations which help to calculate the mass of anthrax at different places at various time.

Model Introduction

$$\begin{pmatrix} \dot{M}_{air} \\ \dot{M}_{tf} \\ \dot{M}_{utf} \\ \dot{M}_{w} \\ \dot{M}_{f} \\ \dot{M}_{ec} \end{pmatrix} = \begin{pmatrix} [(1-e)p-1]\frac{Q}{V}-(\lambda_2+\lambda_3+\lambda_4) & \mu_2 & 0 & 0 & 0 & 0 \\ \lambda_{tf} & -\mu_2 & 0 & 0 & 0 & 0 \\ \lambda_{utf} & 0 & 0 & 0 & 0 & 0 \\ \lambda_{w} & 0 & 0 & 0 & 0 & 0 \\ ep\frac{Q}{V} & 0 & 0 & 0 & 0 & 0 \\ (1-p)\frac{Q}{V} & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} M_{air} \\ M_{tf} \\ M_{utf} \\ M_{w} \\ M_{f} \\ M_{ec} \end{pmatrix}$$

Haas, (2002), argues that the exponential model is appropriate

$$\text{risk} = 1 - \exp(-r \times dose)$$

where risk is the probability of mortality, r is a parameter and dose is the average inhaled dose which equals

$$dose = \int Inh \times Cair(t)dt$$

Haas, (2002) estimates r as 7.16×10^{-6} , when using the data from Druett, (1953) and 2.6×10^{-5} when using the data from Brachman, (1966). In the following simulations we assume an initial release of 1000 spores.

At low risk level, the exponential model can be rewritten in the following expression after Taylor expansion, when the product of r and dose is relatively small,

$$\text{risk} = r \times dose$$

Table 1-a Parameters used in simulations Aerosol

Symbol	Meaning	units	Value
Mt	Mass of anthrax at different place	spores	
V	Volume of office	m^3	$5.6\times5.6\times2.5$
A_{tf}	Area-tracked floor	m^2	$5.6\times5.6\times0.25$
A_{utf}	Area-untracked floor	m^2	$5.6\times5.6\times0.75$
A_w	Area- wall	m^2	$5.6\times2.5\times4$
A_f	Filter area	m^2	0.0382
ACH	Air changes per hour		4
Q	Discharge from the air compartment	m^3/min	5.2267
e	Efficiency of the filter at removing particles		
Inh	Breathing rate	m^3/hr^{-1}	1.02
P	Proportion tracked		0.25

Table 1-b Parameters used in simulations Aerosol

Aerosol diameter (micrometers)						
Symbol	Meaning	Units	1	3	5	10
μ_2	Resuspension	h^{-1}	1.2×10^{-4}	1.9×10^{-3}	8.8×10^{-3}	0.4×10^{-2}
λ_{tf}	Deposition on tracked floor	h^{-1}	0.025	0.15	0.5	2.025
λ_{utf}	Deposition on untracked floor	h^{-1}	0.075	0.45	1.5	6.075
λ_w	Deposition on walls	h^{-1}	0.1	0.4	0.8	0.9
e	Filter efficiency		0.098	0.49	0.74	0.88

Results

Retrospective Simulation. By assuming an average breathing rate and checking anthrax concentration at different surface, we estimate the likely number of anthrax spores inhaled and use dose response models to estimate the probability risk of mortality.

Formula for risk of mortality based on concentration of anthrax on untracked floor:

$$risk = r \times \frac{Inh \times A_{utf} \times C_{utf}}{\lambda_{utf} \times V}$$

Formula for risk of mortality using concentration of anthrax on HVAC filter:

$$risk = r \times \frac{Inh \times A_f \times C_f}{e \times p \times Q}$$

Table 2 Retrospective Scenario: Surface concentration corresponding to a risk level of 10^{-3} for an 8 hour exposure.

Diameter (μm)	r	Concentration (spores/m²)	
		Untracked floor	Filter
1	$r_1=2.6\times10^{-5}$	10	2.4×10^4
1	$r_2=7.16\times10^{-6}$	34	8.8×10^4
3	$r_1=2.6\times10^{-5}$	57	1.2×10^5
3	$r_2=7.16\times10^{-6}$	2.1×10^2	4.4×10^5
5	$r_1=2.6\times10^{-5}$	19×10^2	1.8×10^5
5	$r_2=7.16\times10^{-6}$	6.9×10^2	6.7×10^5
10	$r_1=2.6\times10^{-5}$	7.7×10^2	2.2×10^5
10	$r_2=7.16\times10^{-6}$	2.8×10^3	7.9×10^5

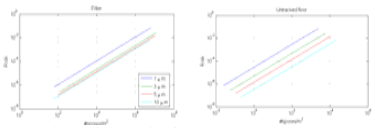

Figure 2 The relationship of retrospective risk and surface concentration for an 8 hour exposure.

Prospective Simulation. The *B. anthracis* is initially on the tracked surface, which corresponds to a post-event scenario following settling; the anthrax has dispersed and settled to a pseudo-equilibrium state. Exposure occurs over an infinite time period (all of the anthracis is eventually reaerosolized) and risk is related to initial surface concentration.

For the prospective scenario, the formula for the risk of mortality based on amount of initial released anthrax on the tracked floor; where C is a function of particle property, HVAC filter efficiency and its recirculation rate:

$$\text{risk} = r \times \frac{Init \times Inh}{Vol} \times C$$

Table 3 Prospective Scenario: Initial surface concentration corresponding to a risk level of 10^{-3}
Time=∞

Diameter (μm)	r	Initial release (spores)
		Tracked floor
1	$r_1=2.6\times10^{-5}$	3.8×10^3
1	$r_2=7.16\times10^{-6}$	1.4×10^4
3	$r_1=2.6\times10^{-5}$	9.5×10^3
3	$r_2=7.16\times10^{-6}$	3.5×10^4
5	$r_1=2.6\times10^{-5}$	1.6×10^4
5	$r_2=7.16\times10^{-6}$	5.9×10^4
10	$r_1=2.6\times10^{-5}$	2.1×10^4
10	$r_2=7.16\times10^{-6}$	1.1×10^5

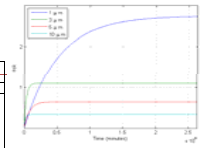

Figure 3 Prospective risk against time for 5 years exposure
(amount of anthrax is 3800 spores)

Conclusion

1. For prospective and retrospective scenarios, the risk of mortality can be linked with the concentration of anthrax on surfaces and HVAC filters.

2. Accurately measuring these levels presents an analytical challenge. Detecting well-aerosolized *B. anthracis* (diameter of 1 μM) will be particularly problematic.

3. This analysis does not account for decay over time, recovery, or discounting of future risk.

References

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