LA-UR- 11-29-10

Approved for public release;
distribution is unlimited.

Title: Predicting Reaerosolization

Author(s): W. Brent Daniel
Kristin M. Omberg

Intended for: 4th National Bio-Threat Conference

Los Alamos
NATIONAL LABORATORY
EST. 1943

Title: **Reaerosolization: What are the primary causes? Can we predict it?**

Conference Topic: Detection, Characterization, and Clearance Sampling and Analysis: An Integrated Approach

Name: Brent Daniel

Contact: wdaniel@lanl.gov

Outdoor studies of the environmental persistence of bacteria have led to many interesting results. It turns out that the initial deposition of bacteria is not the end of the story! We examined both the ongoing daily deposition and aerosolization of bacteria for two weeks following an initial deposition event. Differences between samples collected in a clearing and those collected beneath a forest canopy were also examined. There were two important results: first, bacteria were still moving about in significant quantities after two weeks, though the local environment where they were most prevalent appeared to shift over time; second, we were able to develop a simple mathematical model that could fairly accurately estimate the average daily airborne concentration of bacteria over the duration of the experiment using readily available environmental information. The implication is that deposition patterns are very likely to shift over an extended period of time following a release, possibly quite significantly, but there is hope that we may be able to estimate these changes fairly accurately.

Predicting Reaerosolization

Brent Daniel, Kristin Omberg

Motivation

- **How long does an exposed area remain contaminated?**

Motivation

- How long does an exposed area remain contaminated?
- **Does material reaerosolize and present and inhalation risk?**

Motivation

- How long does an exposed area remain contaminated?
- Does material reaerosolize and present and inhalation risk?
- **In what quantity? For how long?**

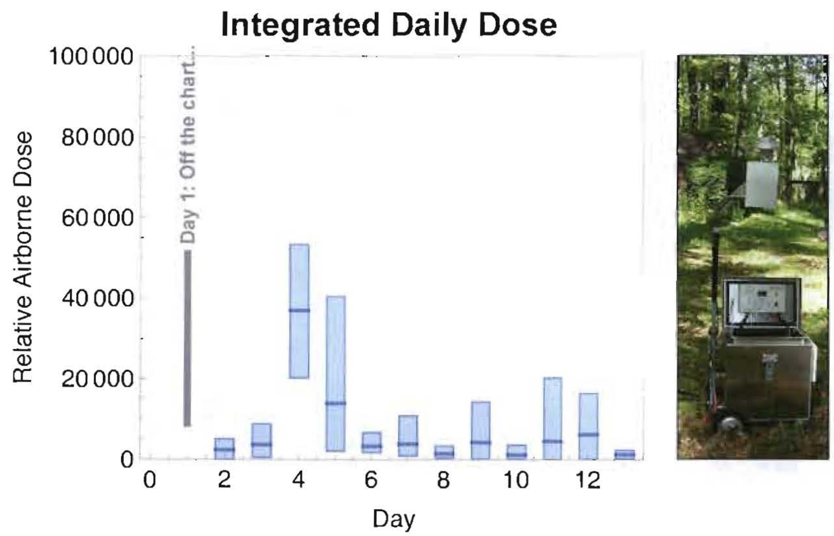
Motivation

- How long does an exposed area remain contaminated?
- Does material reaerosolize and present and inhalation risk?
- In what quantity? For how long?
- **What environmental factors play a role?**

Motivation

- How long does an exposed area remain contaminated?
- Does material reaerosolize and present and inhalation risk?
- In what quantity? For how long?
- What environmental factors play a role?
- **If these quntities do vary over time, can they be predicted with enough accuracy to help guide/inform policy/response decisions?**

Approach



Empirical Observation

$$\frac{d\sigma}{dt} = u_g c - \frac{A\rho}{gh} u_*(u_*^2 - u_{*t}^2)\frac{\sigma}{\sigma_0}$$

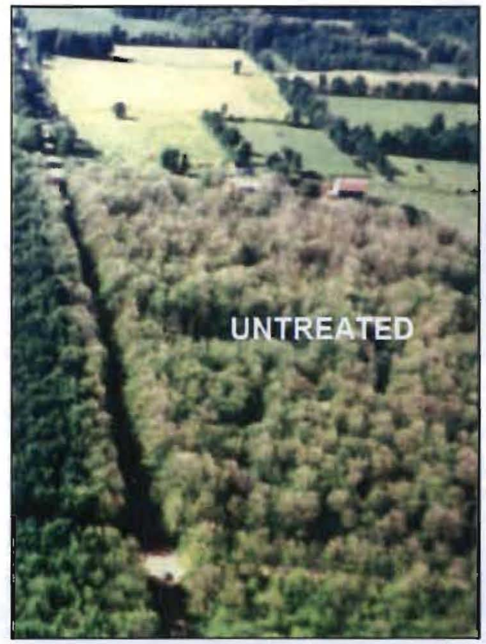
$$\frac{dc}{dt} = -h^{-1}\frac{d\sigma}{dt} - L^{-1}uc$$

Theoretical Model

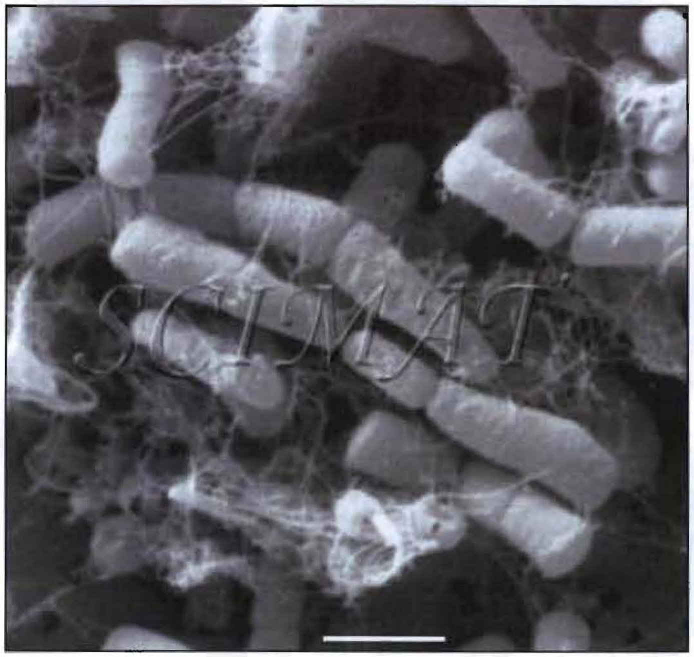
The Gypsy Moth

The Asian Gypsy moth (Lymantria dispar) is an invasive species that was introduced from Europe in the 1860s

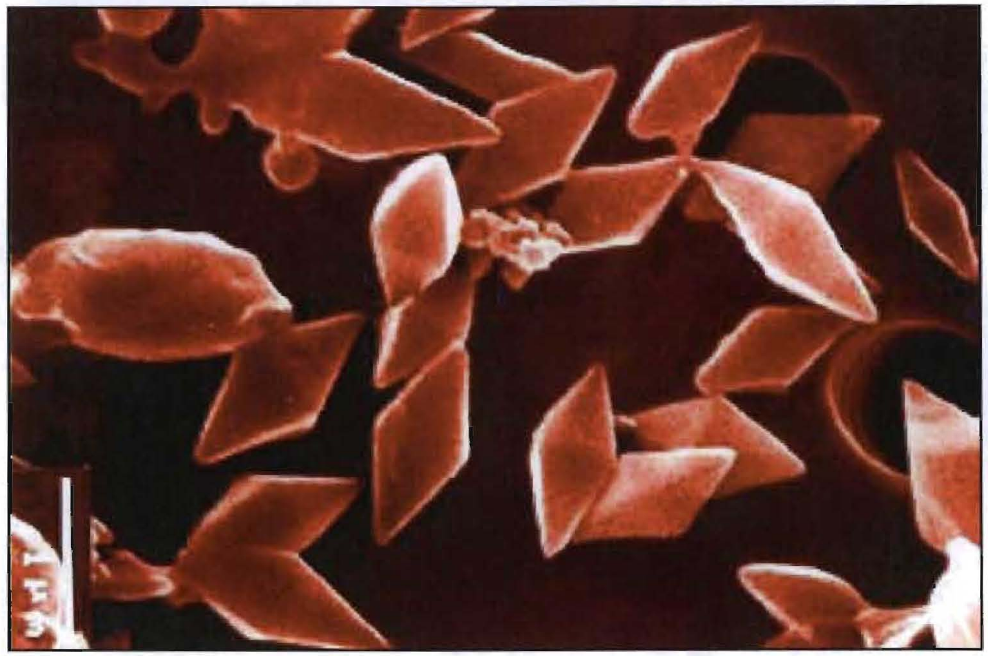
Native tree species haven't evolved defenses



Mitigation



Bacillus thuringiensis var. kurstaki

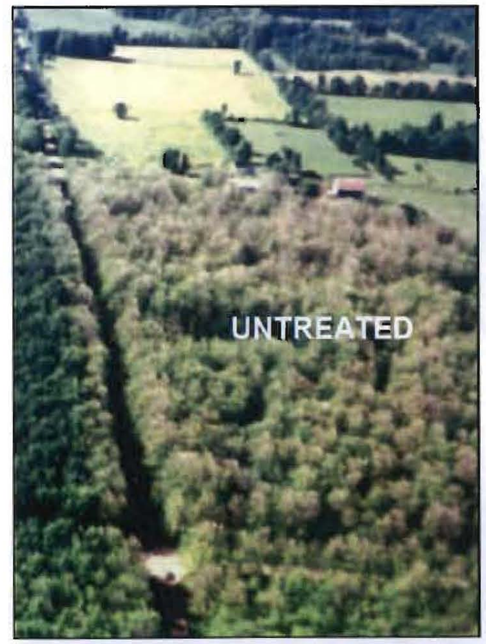


Bt toxin is pathogenic to Gypsy Moths

The Gypsy Moth

The Asian Gypsy moth (Lymantria dispar) is an invasive species that was introduced from Europe in the 1860s

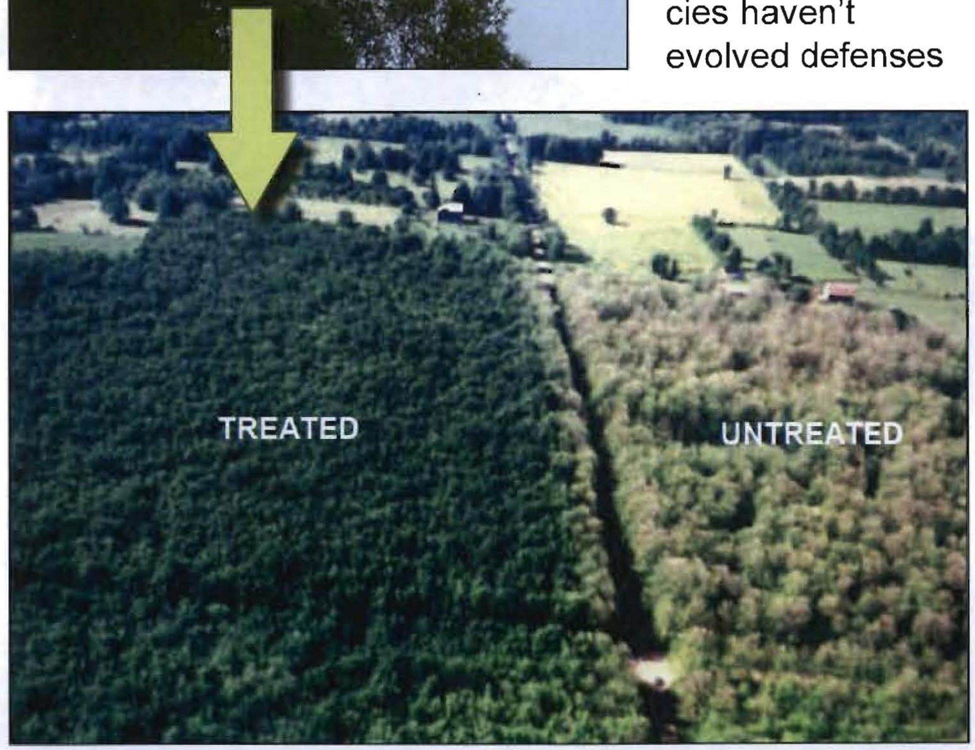
Native tree species haven't evolved defenses



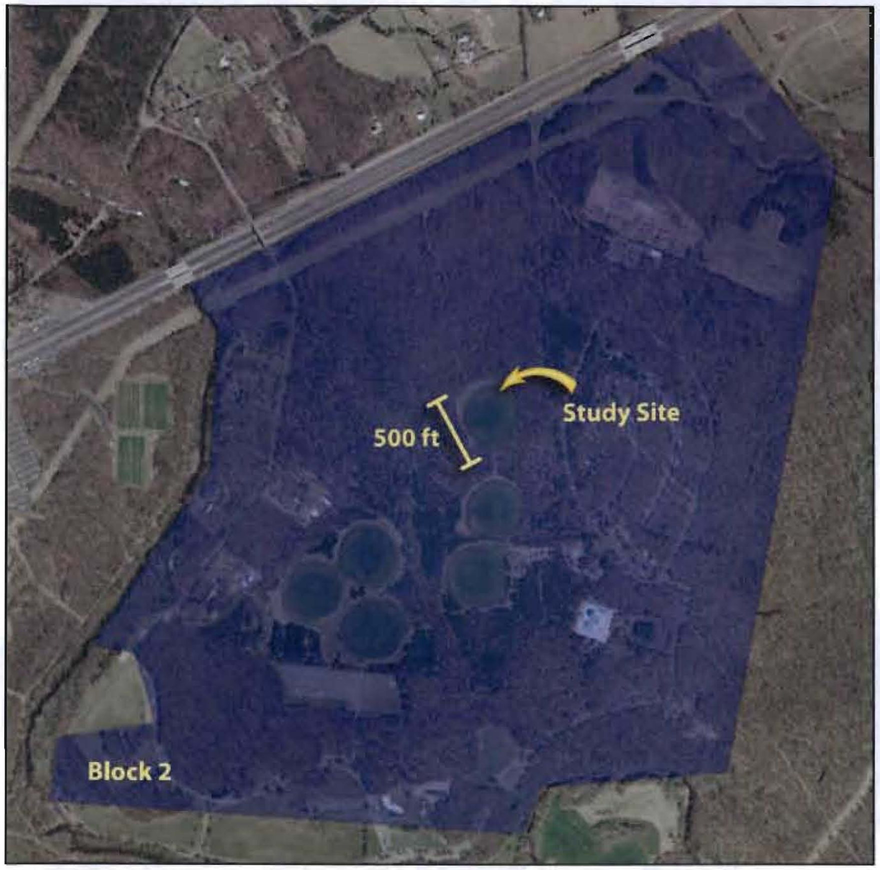
The Gypsy Moth

The Asian Gypsy moth (Lymantria dispar) is an invasive species that was introduced from Europe in the 1860s

Native tree species haven't evolved defenses



Experiment



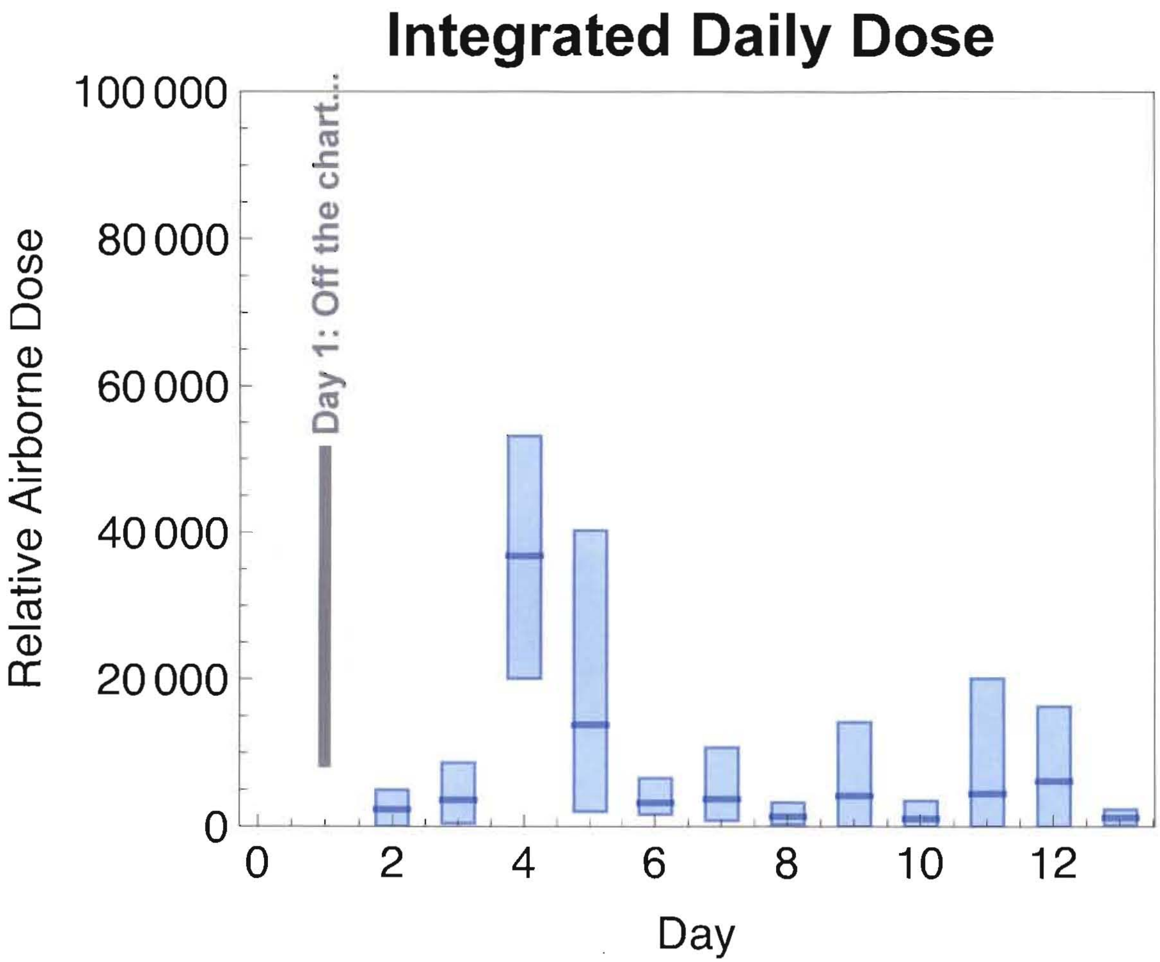
A one square mile spray block in suburban Virginia

Close-up of study area

Experiment

Aerosol collectors used to measure daily airborne does. Samples collected every twenty-four hours for almost two weeks.

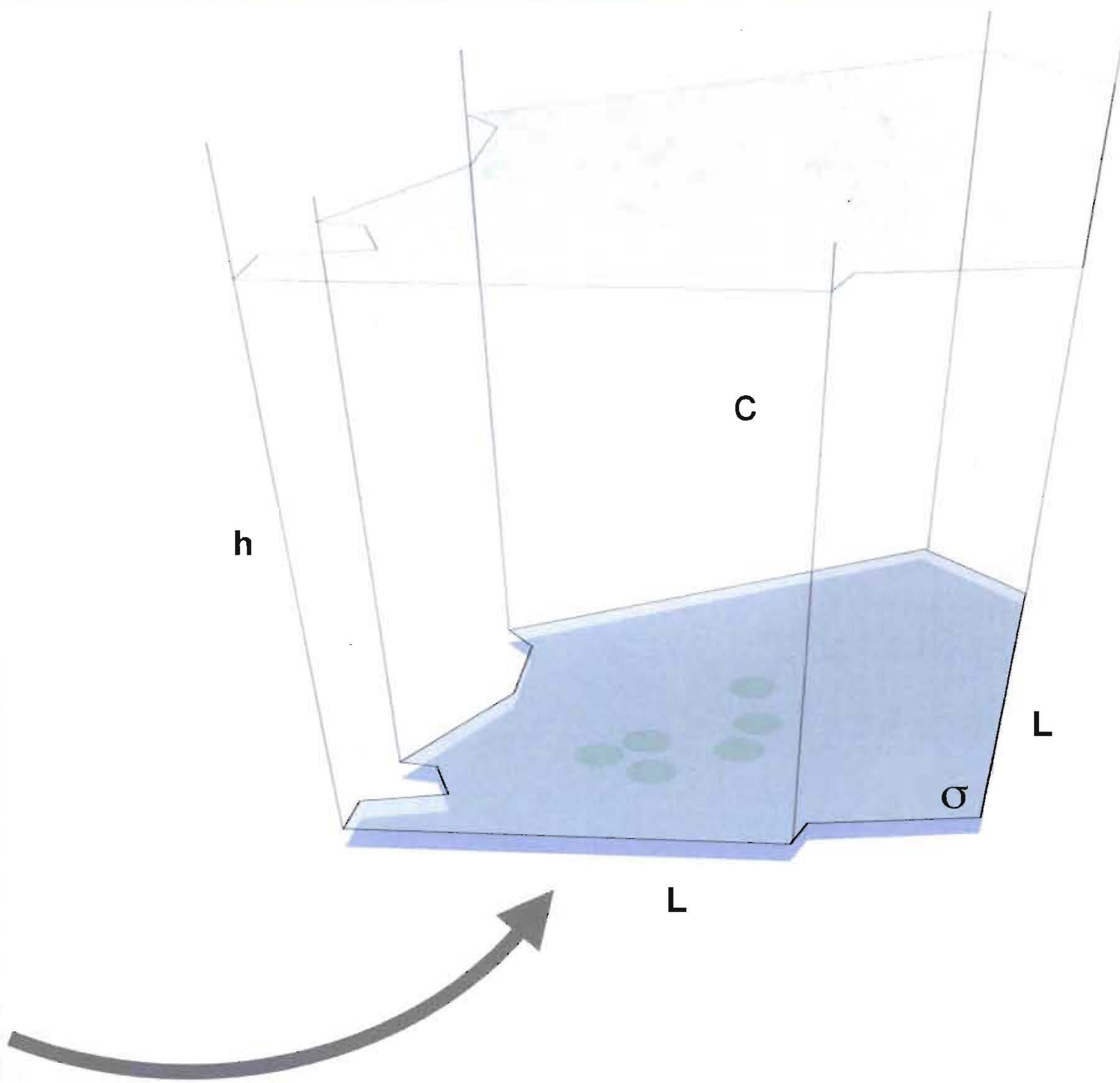
Empirical Observation



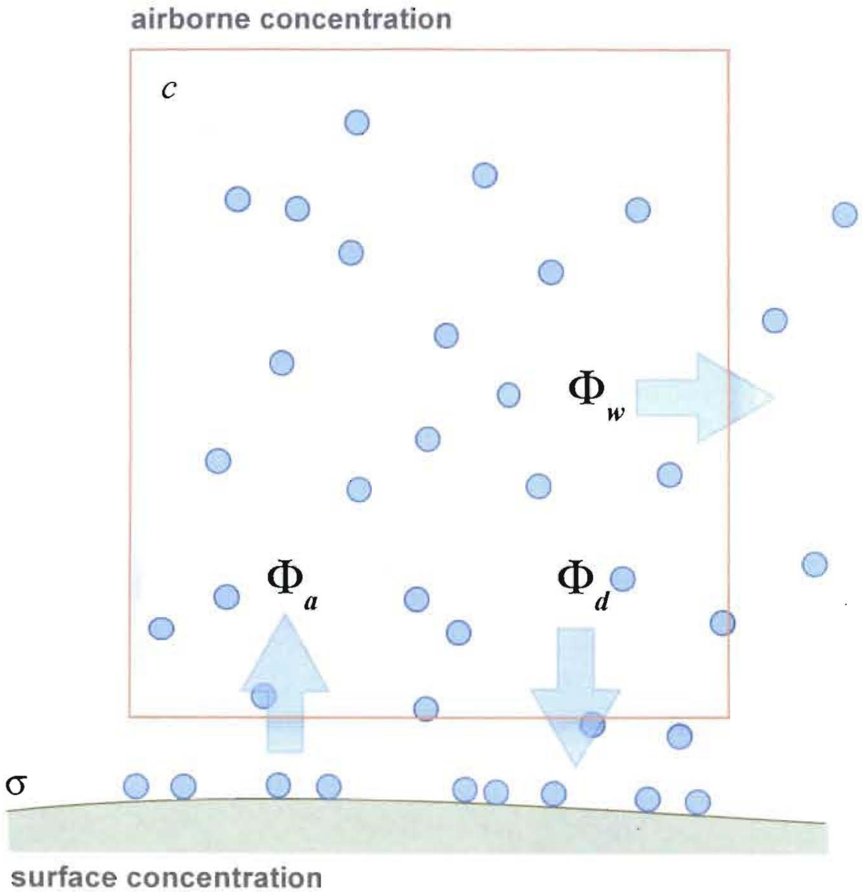
- How long does an exposed area remain contaminated?
- Does material reaerosolize and present and inhalation risk?
- In what quantity? For how long?
- What environmental factors play a role?
- If these quntities do vary over time, can they be predicted with enough accuracy to help guide/inform policy/response decisions?

Theory

- How does the concentration in the volume above the contaminated area change over time?
- How does the surface concentration change over time?



Material Conservation



Mass conservation in box

$$L^2 h \frac{dc}{dt} = L^2 \Phi_a - L^2 \Phi_d - L h \Phi_w$$

$$\frac{dc}{dt} = h^{-1} \left[\Phi_a - \Phi_d \right] - L^{-1} \Phi_w$$

Mass conservation at surface

$$L^2 \frac{d\sigma}{dt} = L^2 \Phi_d - L^2 \Phi_a$$

$$\frac{d\sigma}{dt} = \Phi_d - \Phi_a$$

Particle Flux

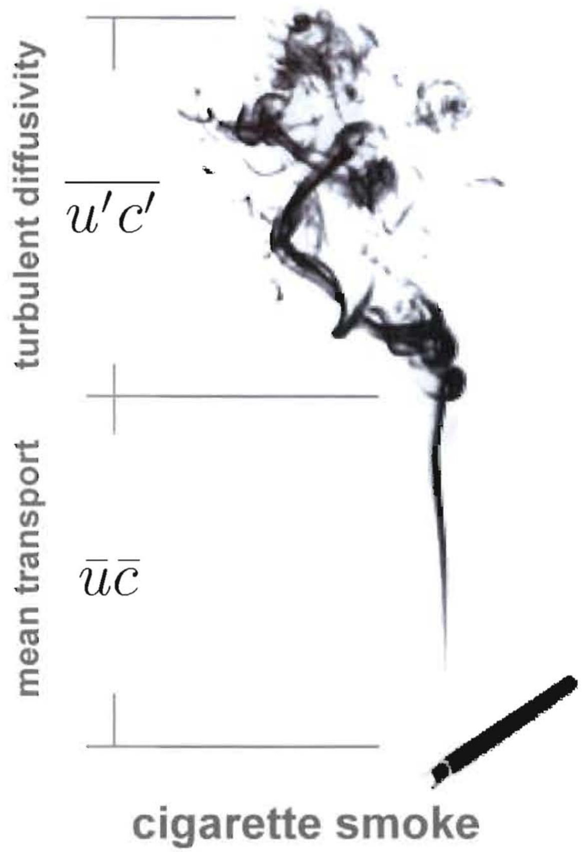
Now, we must define each of these fluxes. In general, the contributions come from the following terms:

$$\Phi = \bar{u}\bar{c} + \overline{u'c'} - u_g\bar{c} - D\frac{\partial \bar{c}}{\partial z}$$

Particle Flux

Now, we must define each of these fluxes. In general, the contributions come from the following terms:

$$\Phi = \bar{u}\bar{c} + \overline{u'c'} - u_g\bar{c} - D\frac{\partial \bar{c}}{\partial z}$$



Particle Flux

Now, we must define each of these fluxes. In general, the contributions come from the following terms:

$$\Phi = \bar{u}\bar{c} + \overline{u'c'} - u_g\bar{c} - D\frac{\partial \bar{c}}{\partial z}$$

Thermal diffusion

Gravity-driven settling

Particle Flux: Wind and Deposition

no vertical component

Wind: $$\Phi = \bar{u}\bar{c} + \overline{u'c'} - u_g\bar{c} - D\frac{\partial \bar{c}}{\partial z}$$

concentration relatively uniform near block center

minuscule on time and length scales we're talking about

could be important; largely serves to reduce deposition rate here

Deposition: $$\Phi = \bar{u}\bar{c} + \overline{u'c'} - u_g\bar{c} - D\frac{\partial \bar{c}}{\partial z}$$

minuscule on time and length scales we're talking about

Particle Flux: Reaerosolization

particle availability
air density
particle surface density

$$\Phi_a = \frac{A\rho}{gh} u_* (u_*^2 - u_{*t}^2) \frac{\sigma}{\sigma_0}$$

threshold friction velocity
gravitational acceleration

From mass and momentum conservation of air/particle system

von Karman constant
wind speed

$$u_* = \frac{ku}{\ln\left(\frac{z - d_0}{z_0}\right)}$$

surface roughness
wind observation height
friction velocity

From similarity theory

P.R. Owen, Journal of Fluid Mechanics **20**, 225 (1964)

D.A. Gillette, *et al.*, Earth Surface Processes and Landforms **21**, 641 (1996)

Putting It All Together

Conservation Equations

$$\frac{dc}{dt} = h^{-1}\left[\Phi_a - \Phi_d\right] - L^{-1}\Phi_w$$

$$\frac{d\sigma}{dt} = \Phi_d - \Phi_a$$

$$\Phi_w = u_w c$$

$$\Phi_a = \frac{A\rho}{gh} u_* (u_*^2 - u_{*t}^2) \frac{\sigma}{\sigma_0}$$

$$\Phi_d = u_g c$$

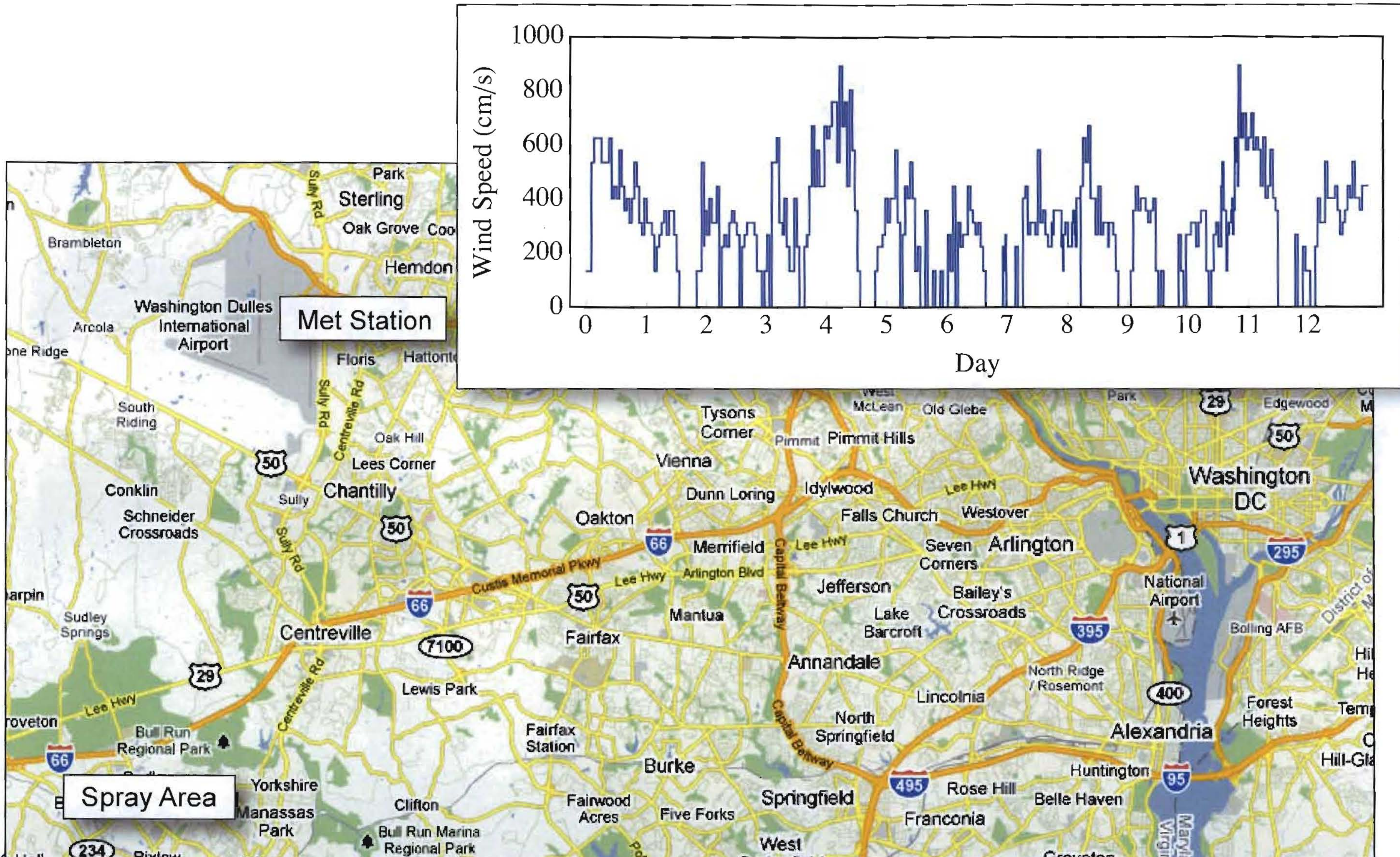
$$\frac{d\sigma}{dt} = u_g c - \frac{A\rho}{gh} u_* (u_*^2 - u_{*t}^2) \frac{\sigma}{\sigma_0}$$

$$\frac{dc}{dt} = -h^{-1}\frac{d\sigma}{dt} - L^{-1} uc$$

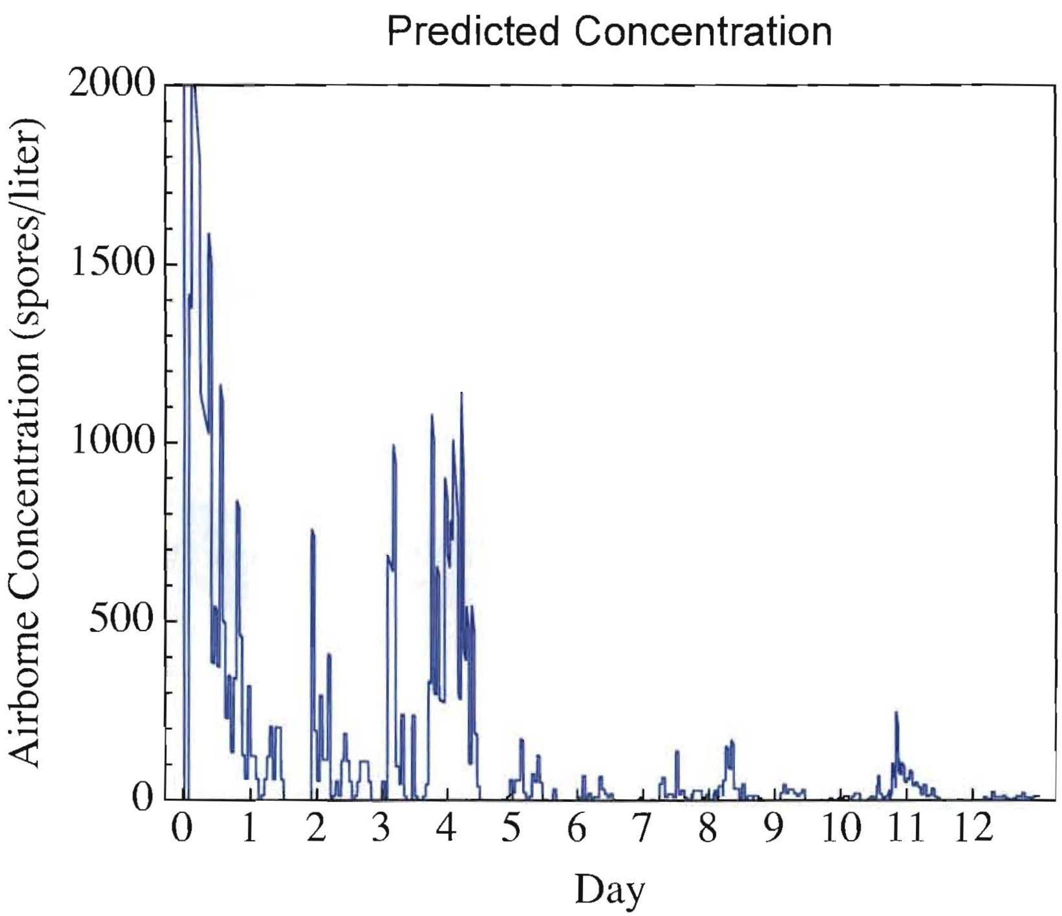
Constants

s_0 = 0 spores / cm^2
c_0 = 562 spores / cm^3
u_g = 15 cm / s
u_{*t} = 12 cm / s
h = 2500 cm
A = 1.36

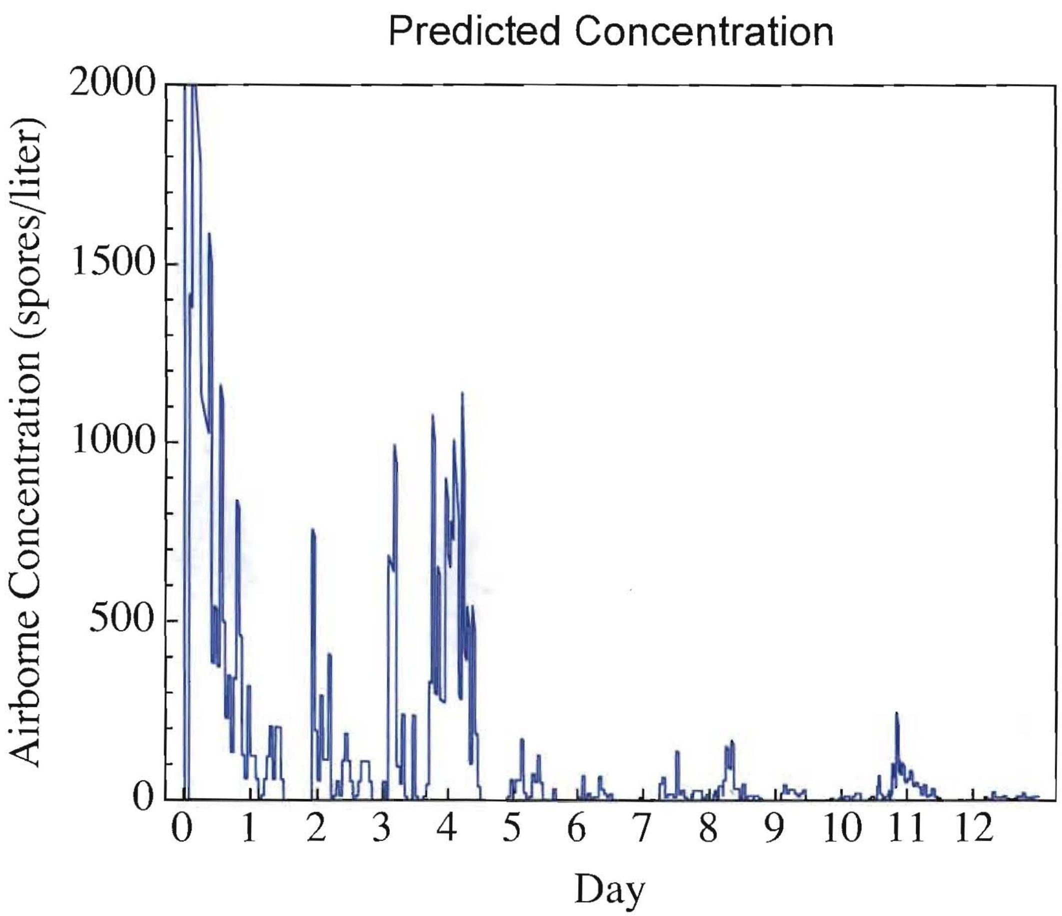
Meteorological Data



Airborne Concentration



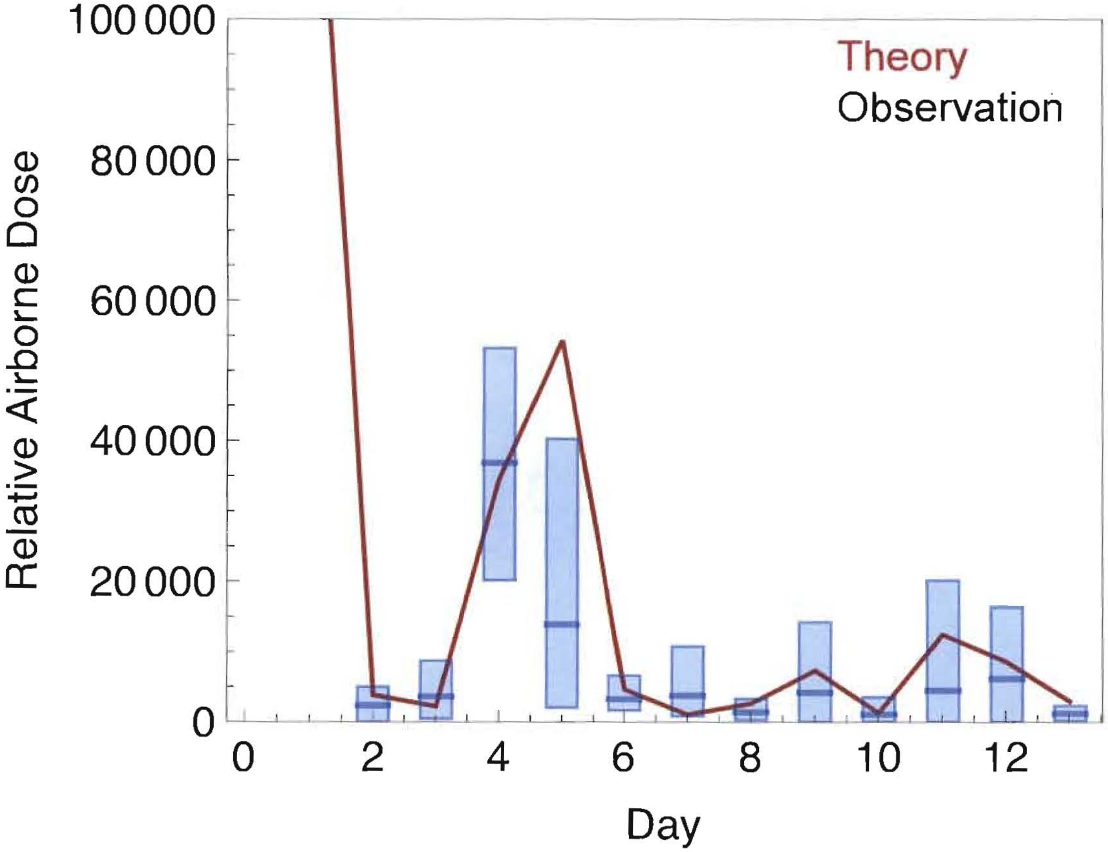
Airborne Concentration



The dose is the airborne concentration integrated over the sample collection period:

$$d = \int_{t}^{t+T} dt\ c(t)$$

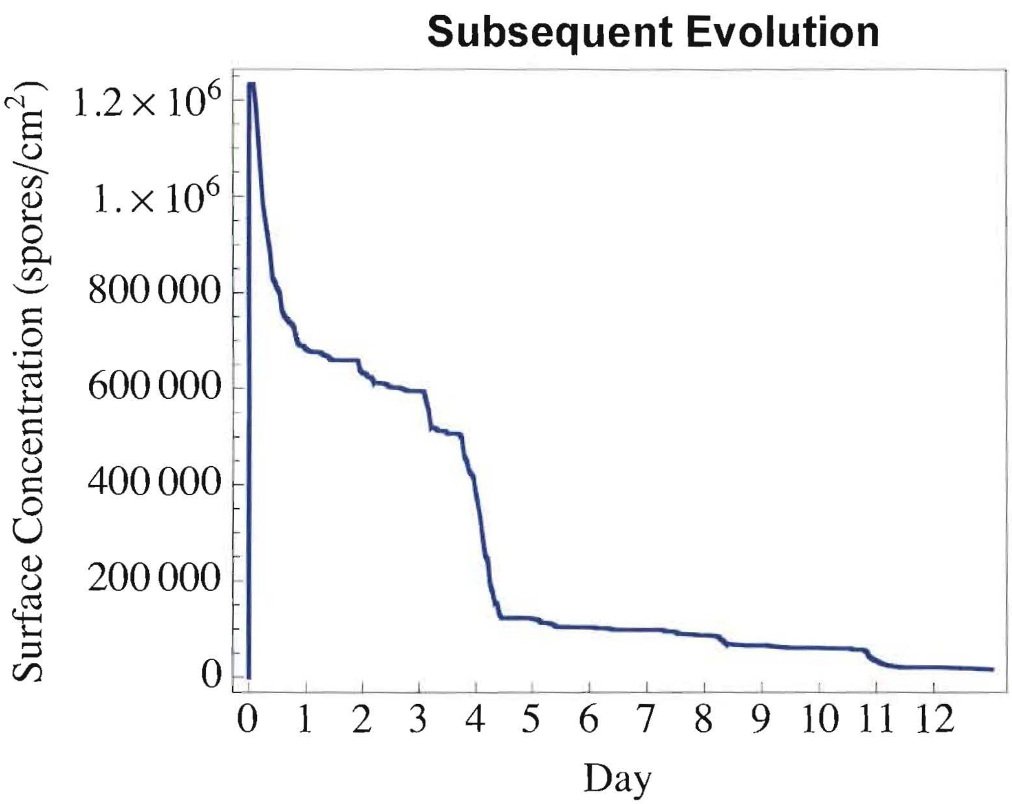
Airborne Concentration



The dose is the airborne concentration integrated over the sample collection period:

$$d = \int_t^{t+T} dt\, c(t)$$

Surface Concentration Estimates



Conclusions

- Deposited material can reaerosolize in significant quantities
- Contaminated area and associated re-mediation needs evolve daily
- Reaerosolization rate depends strongly on wind speed
- Relatively simple model can provide fairly accurate quantitative estimates of critical contamination metrics