Validation of the Well-Mixed Room Constant Generation Rate Model for a Fibrous Aerosol

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Objective

Demonstrate the effect of ventilation on exposure.
Goal

To develop a model to use with low level airborne asbestos fiber data to estimate asbestos exposure concentrations under various ventilation rates.
Research

Models for Predicting Occupational Exposures

- Mathematical Models for Estimating Asbestos Exposure
  - One Study published in a Journal
    - Esmen, Nurtan A; Corn, Morton, Airborne Fiber Concentrations During Splitting Open and Boxing Bags of Asbestos, *Toxicol Ind Health*, 14:6 (Nov 1998); 843-856

- Mathematical Models for Estimating Exposure to Aerosols
  - EPA Indoor Air Quality Models

- Gas, Vapor Well Mixed Room with Constant Emission Rate
  - Estimates concentration at a given time.
  - Can calculate a TWA from the estimate.
Ventilation Models Using Tracer Gas

- Published Ventilation Models using Tracer Gas
  - Selection of tracer gas.
  - Carbon dioxide
  - Selection of method.
  - Concentration Decay Test Method
Research Results

- Established methods for testing ACH with tracer gas.
- Existing aerosol models are complex and not well suited to model asbestos concentrations.
- With low concentrations of fibers, the well mixed constant emission rate gas vapor model may be appropriate.
Well Mixed Room Model (WMRM) Assumptions

Constant Emission Rate

Considerations:
- Few sources satisfy the description.
- Fails to capture the intensity of peak or short-term exposures.
- Should not be used if peak exposures are important in terms of toxicology and/or regulation.

Nevertheless:
- This model is reasonable if toxicological and/or regulatory interest focuses on the 8 hour TWA exposure level.
- If the same total contaminant mass is released into room air either as one pulse, a series of smaller pulses, or uniformly over the shift, the shift-average concentration in room air will be nearly the same.
Well Mixed Room Model Assumptions

Well Mixed Room Considerations:

- The model considers that a room is a perfectly mixed box
  - Perfect mixing means the contaminant is dispersed instantaneously throughout the room to create a uniform concentration.
  - For example, the concentration is the same at 1cm versus 10m from the source.

- Perfect mixing is physically unrealistic
  - Perfect mixing assumption can lead to underestimating exposure intensity for individuals located close to a point source if personal exposure data is unavailable.
  - In other words, using the model without validation can lead to underestimating exposures.
Well Mixed Room Model

- Model considers 2 possible contaminant removal pathways.

1. The exhaust air flow at rate $Q \text{ (m}^3\text{/min)}$.
   - Measurable

2. Gravitational settling
   - Difficult to estimate or measure.
   - Usually considered negligible.
A Quote Attributed to Albert Einstein

“Things should be kept as simple as possible, but not simpler.”

In our study, we chose to validate the simplest model.
Well Mixed Room Model - Constant Contaminant Emission Rate

\[
C(t) = \frac{G + C_{IN}}{Q + k_L \cdot V} \left[ 1 - \exp \left( -\frac{Q + k_L \cdot V}{V} t \right) \right] + C_0 \exp \left( -\frac{Q + k_L \cdot V}{V} t \right)
\]

**Input Variables**

- \(C_{IN}\) mg/m³: Concentration in incoming air
- \(G\) mg/min: Generation Rate
- \(Q\) m³/min: Exhaust air flow
- \(V\) m³: Volume of Room
- \(K_L\) per min: Loss Pathway (sinks)
- \(C_0\) mg/m³: Initial concentration
Schematic of WMRM System
Ventilation Rate Measurement Using Tracer Gas

- Carbon dioxide gas introduced then measured using the Concentration Decay Test Method to calculate the air change rate.
- Carbon Dioxide
  - Easy to use and measure.
  - High TLV - 5000 ppm
Isolation Chamber

- Approximately 20’ x 20’ x 9’ (3600 ft³)
- Wood Frame
- Polyethylene sheeting on walls and floors
- 2 viewing windows
- Entrance Airlock
- Decontamination Shower
- HEPA Filtered Exhaust Machines for Ventilation
HEPA Filtered Exhaust Machines for Chamber Ventilation System

Note: Using various configurations, both machines operated as exhaust.
Direct Reading Equipment

TSI Q-Trak
Log CO₂ Data
Carbon Dioxide Concentration (ppm) vs Time

B & Y Test Chamber
5.7 Air Changes Per Hour
April 29, 2003

Trial 1 – 5.8 ACH
Trial 1 – 5.8 ACH
Trial 2 – 5.8 ACH
Trial 2 – 5.5 ACH

Average 5.7
Aerosol Generator and Testing Equipment

- Equipment to generate fibers for the tests.
- Direct reading equipment.
- Standard air sampling methods - NIOSH 7400 analysis by PCM.
Aerosol Generator

- Fluidized Bed Aerosol Generator
- TSI Model 3400 A
- Recommended by NIOSH staff with experience conducting aerosol research with asbestos fibers.
Aerosol Generator

- Capable of a constant output and concentration.
- Used for inhalation and toxicology studies.
- Fluidized bed chamber and powder reservoir.
a Aerosol Dust Outlet
b Screw, ¼-2 UNC x ½ in.
   Phillips Pan-Head (4)
c O-ring
d Cyclone
e Elutriator
f Bead Return Nozzle
g Powder Reservoir Cover
h Screw, 10-24 UNC x ½ in.
   Phillips Pan-Head (2)
i O-ring
j Powder Reservoir Cover
   Handle
k Brass Drive Sprocket
l O-ring
m Center Shaft
n Four Bar Follower Disk
o Pivot Pin
p Powder Reservoir End Cover
q Rake Rods
r Powder Reservoir
s Scraper Rod
t Powder Supply Nozzle
u O-ring
v Snap Ring
w Porous Plate
x Base
y Air Plenum Chamber
z Inlet for Regulated Air Fitting
aa O-rings
bb Direction of Chain
cb Idler Pulley Assembly
dd Bead Chain
ee O-ring
ff Screw, ¼-20 UNC x ¾ in. Phillips Pan-Head
gg Fluidized Bed Chamber
Aerosol Generator Process
Aerosol Generator

- Grade 7M used for the first tests.
- No measurable asbestos fiber concentration was generated.
- Grade “shorts” used for the second tests and still no measurable asbestos fiber was generated.
- Only a very small amount of material was being placed in the bead bed by the bead chain. Chain speed did not matter.
- Generating asbestos concentration using this method was unsuccessful.
Aerosol Generator

- Modified the generator system by placing a measured mass of asbestos “shorts” directly into a measured mass of brass beads in the bead bed at the base of the elutriator.
- Flow rate from the generator was adjusted to 10 lpm.
- Asbestos shorts (aka “floats”) was used for the study.
- Method was successful in generating a consistent asbestos fiber concentration.
Fibrous Aerosol Monitor (FAM)  
(a footnote in the study)

Real-time monitoring instrumentation for rapid, continuous measurement of airborne asbestos fiber concentrations.
Fibrous Aerosol Monitor Results

Fibrous Aerosol Monitor
Fiber Concentration vs. Time at 10.7 Air Changes Per Hour
May 20, 2003

0.006 f/cc – maximum result
No correlation to analytical results.
Isolation Chamber Equipment and Sample Locations

- Entrance airlock
- Fibrous Aerosol Monitor
- Aerosol Generator
- HEPA Filtered Exhaust Machine
- HEPA Filtered Exhaust Machine

Sample # - Height
1 – 1 ft.
2 – 3 ft.
3 – 6 ft.
4 – 5 ft.
5 – 7 ft.
6 – 6 ft.
7 – 2 ft.
8 – 8 ft.
Testing in the Isolation Chamber
Generation Rate

- All parameters of each test were the same except for the ventilation rate of the chamber.
- The generation rate was consistent from test to test as evidenced by the results.
- Mathematical model used to calculate generation rate
- Determined to be 0.008 mg/min
Conversions

- 30 fibers = 1 ng
- f/cc ÷ 30 = mg/m³
- f/cc ÷ 6 = mpcf

Calculations

- \[0.008 \text{ mg/min} \times \frac{1 \text{ gram}}{1000 \text{ mg}} \times 10^9 \text{ ng/gram} \times 30 \text{ fibers/ng}\]
  \[= 240,000 \text{ fibers/min}\]
- Test time of 248 minutes = 59,520,000 fibers generated during test
Predicted Concentration (f/cc)
Measured Average Concentration (f/cc)
at 10.7 Air Changes Per Hour
May 20, 2003

0.0165 f/cc Measured TWA
0.014 f/cc Predicted
15% Difference
Predicted Concentration (f/cc)
Measured Average Concentration (f/cc)
at 5.7 Air Changes Per Hour
May 20, 2003

0.029 f/cc Measured TWA
0.025 f/cc Predicted
14% Difference
Predicted Concentration (f/cc)
Measured Average Concentration (f/cc)
at 2.9 Air Changes Per Hour
May 21, 2003

0.048 f/cc Measured TWA
0.047 f/cc Predicted
2% Difference
Predicted Concentration (f/cc)
Measured Average Concentration (f/cc)
at 1.2 Air Changes Per Hour
May 21, 2003

- Predicted Concentration (0.124 f/cc)
- Predicted TWA
- Measured TWA Concentration (0.098 f/cc)

0.098 f/cc Measured TWA
0.10 f/cc Predicted TWA
2% Difference
Predicted, Predicted Average and Measured Average Asbestos Concentration (f/cc) vs Air Changes Per Hour
Limitations and Uncertainty

- Generation rate was determined mathematically.
- Fiber size distribution was not known.
- Stokes’ Law for settling was not taken into account.
- EPA conversion factors were used to go from mg/m3 to f/cc.
Conclusions

- The well mixed room-constant generation rate model was accurately predictive for asbestos exposures under various ventilation rates.

- Validation of the traditional gas/vapor model for low level asbestos exposures has not previously been reported in the literature.

- The FAM does not work well for low asbestos fiber concentrations.

- Carbon dioxide works well as a tracer gas to determine air change rates.

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Thank You

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