A Dynamic Approach to Monitoring Particle Fallout in a Cleanroom Environment

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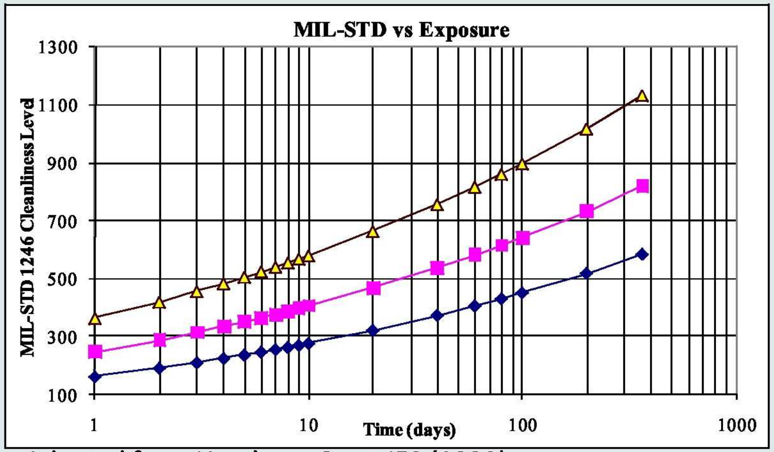
Introduction

- Particle fallout levels are commonly used for:
  - Estimating the effects of environmental exposure of sensitive surfaces
  - Development of contamination budgets
- Standard fallout measurement approaches require durations inversely proportional to the environmental cleanliness
- Cleanrooms are certified according to airborne particle count, and many cleanrooms are equipped with continuous monitoring
- The ability to estimate particle fallout based on airborne particle counts provides a more dynamic approach

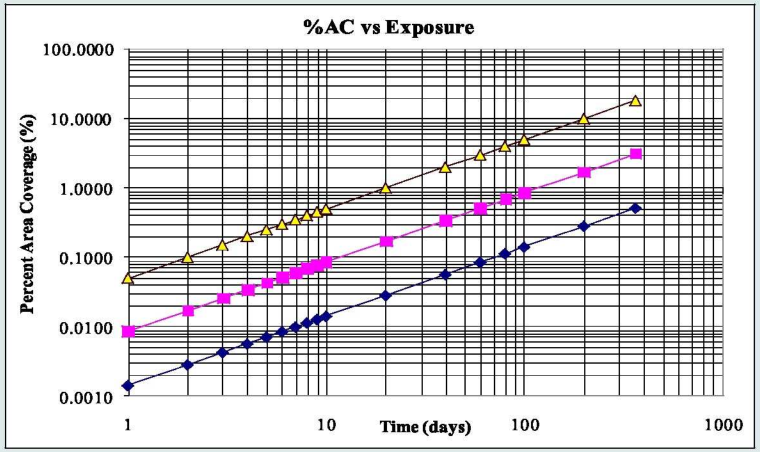
Assumptions

- Fallout rates are directly proportional to air quality
- Rates and quality directly reflect activity levels
- Once settled, particles remain
- Accumulation surfaces are horizontal

Simple Approach



Adapted from Hamburg, Proc. IES (1982)



- Previous studies correlated cleanliness class to cleanliness level
  - Cleanliness level is sensitive to particle distributions
    - MIL-STD 1246 (IEST-STD-CC-1246) cleanliness levels use -0.926 distribution slope
    - Airborne particle distribution follows a -0.28 slope
    - Distribution of particle fallout is -0.383
  - Results in non-linear relationship

- Correlation to a normalized area coverage (e.g. PAC) provides a linear time relationship
- Simple substitution remains non-linear for cleanroom class

Theoretical Components

- Airborne Particle Distribution (FED-STD-209)

$$n_x = Class * \left(\frac{0.5}{x}\right)^{2.2}$$

- Effective Column Height (Stokes Coefficient)

$$\nu = \frac{2 * g * r^2 * (d_1 - d_2)}{9\mu}$$

Caveat: Limit column height by ceiling height and air exchanges

- Obscuration Factor

$$OF = \left(\frac{x}{AR}\right)^2 * \left(\frac{\pi}{4} + AR - 1\right)$$

Particle Size (microns)	Aspect Ratio (L:W)
1 - 69	$X^{0.1088}$
70 - 175	$X^{0.8804}/26.53$
176 - 346	$X^{2.589}/181500$
> 346	$X^{0.8964}/9.138$

Adapted from Ma, Fong, and Lee, SPIE 1165 (1989)

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Putting It All Together

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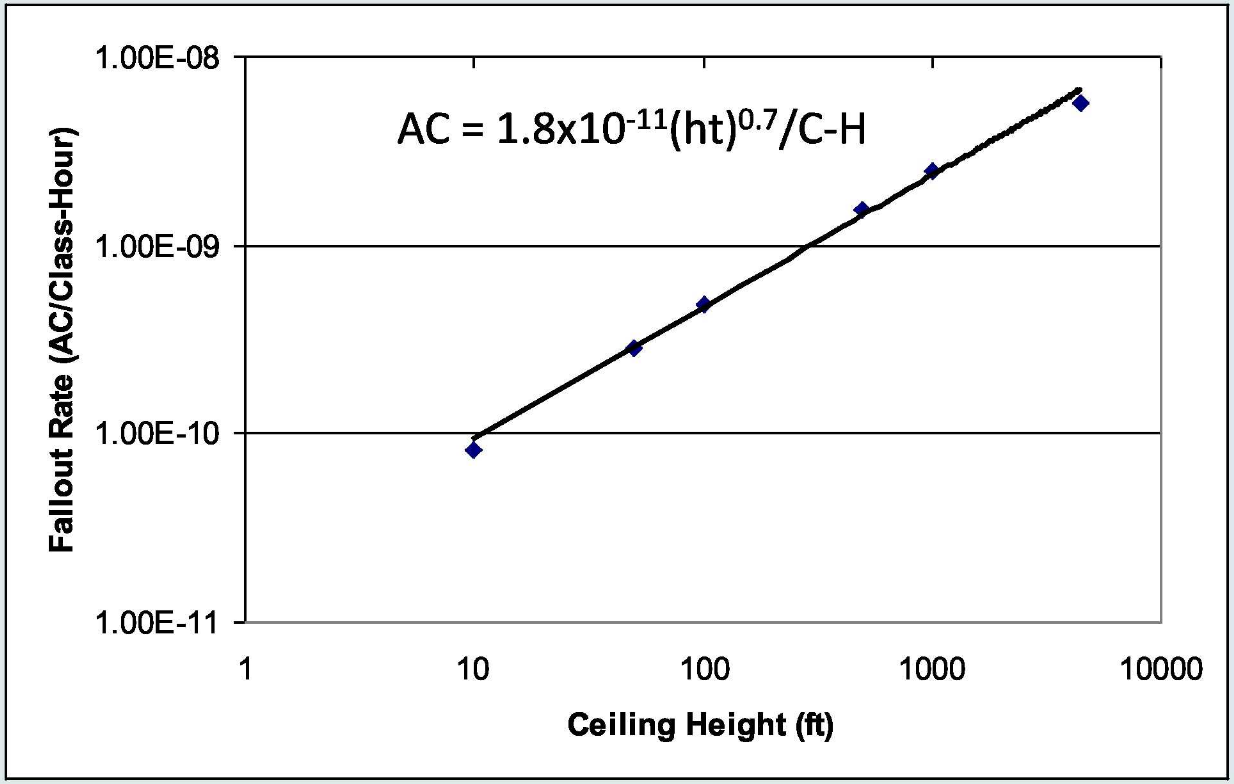
- Combination of distribution, column height, and obscuration factor provides a linear correlation of area coverage (AC) to cleanroom class and time (Class-Hours)

$$AC_x = \left[\frac{n_{x+1} - n_x}{Class}\right] * \left[v(OF) * \frac{3600\,s}{hr} * \frac{ft}{30.48\,cm}\right] * \left[OF * \frac{1.076x10^{-11}\,ft^2}{\mu m^2}\right]$$

- A spreadsheet was used to determine the incremental contribution of AC for particles in 1 micron bins from 1 to 1000 microns

Numerical Results



For ISO 14644-1: $n_x = 10^{Class} * \left(\frac{0.1}{x}\right)^{2.08}$ therefore AC = $4.7 \times 10^{-14}(ht)^{0.81}$/C-H

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How To Make It Work

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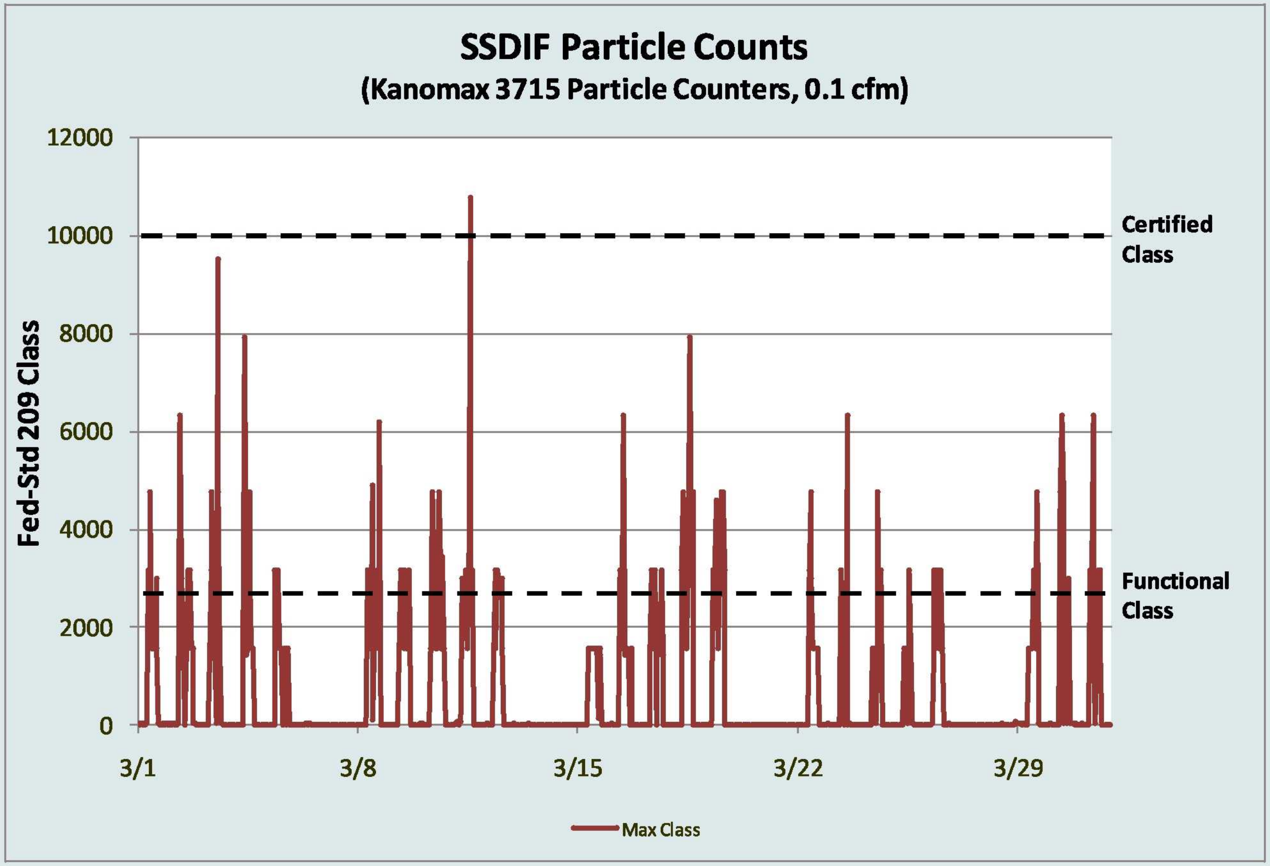
- Predictive:
  - Assume a limit of 0.1 PAC in a facility with a 100 foot ceiling, this results in $2.2x10^6$ Class-Hours
    - For a Class 10K facility: 220 hours
    - For one month duration: Class 3000
  - Assume covering off-shift (2/3 of each day)
    - For a Class 10K facility: 660 hours
    - For one month duration: Class 9000
- Dynamic:
  - Cleanroom environments are rarely static, but vary with activity level
  - Airborne particle counters can provide real-time data

Application



- Hourly monitoring sums to 5.15×10^{5} Class-Hours (>75% margin)

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Supporting Evidence

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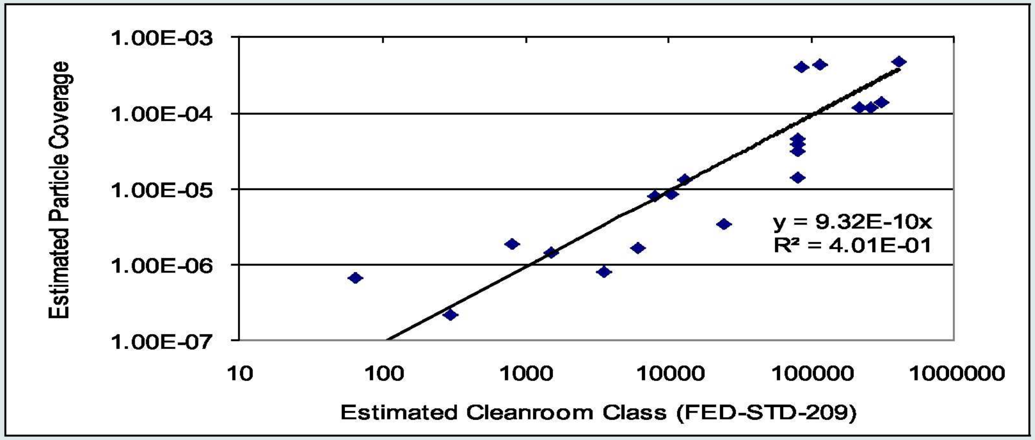
- Ongoing monitoring at GSFC SSDIF
  - Estimated AC/C-H (100 ft ceiling): $4.5\text{x}10^{-10}$
  - *{Estimated AC/C-H (43 exchanges/hr): $5.9\text{x}10^{-9}$}*
  - Measured AC/C-H (5μm channel): $4.9(\pm 8.0)\text{x}10^{-10}$
  - *{Measured AC/C-H (0.5μm channel): $4.6(\pm 9.2)\text{x}10^{-9}$}*
- Hamburg data: $9.3\text{x}10^{-10}$ AC/C-H



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SPIE Optics+Photonics

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