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

- 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)**
  \[ n_x = \text{Class} \times \left(\frac{0.5}{x}\right)^{2.2} \]

- **Effective Column Height (Stokes Coefficient)**
  \[ \nu = \frac{2 \times g \times r^2 \times (d_1 - d_2)}{9 \mu} \]
  *Caveat: Limit column height by ceiling height and air exchanges*

- **Obscuration Factor**
  \[ OF = \left(\frac{x}{AR}\right)^2 \times \left(\frac{\pi}{4} + AR - 1\right) \]

<table>
<thead>
<tr>
<th>Particle Size (microns)</th>
<th>Aspect Ratio (L:W)</th>
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</thead>
<tbody>
<tr>
<td>1 - 69</td>
<td>X^{0.1088}</td>
</tr>
<tr>
<td>70 - 175</td>
<td>X^{0.8804}/26.53</td>
</tr>
<tr>
<td>176 - 346</td>
<td>X^{2.589}/181500</td>
</tr>
<tr>
<td>&gt; 346</td>
<td>X^{0.8964}/9.138</td>
</tr>
</tbody>
</table>

*Adapted from Ma, Fong, and Lee, SPIE 1165 (1989)*
Combination of distribution, column height, and obscuration factor provides a linear correlation of area coverage (AC) to cleanroom class and time (Class-Hours)

\[
AC_x = \left[ \frac{n_{x+1} - n_x}{\text{Class}} \right] \times \left[ \nu_{OF} \times \frac{3600 \text{ s}}{\text{hr}} \times \frac{\text{ft}}{30.48 \text{ cm}} \right] \times \left[ OF \times \frac{1.076 \times 10^{-11} \text{ ft}^2}{\mu m^2} \right]
\]

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: \[ n_x = 10^{\text{Class}} \times \left( \frac{0.1}{x} \right)^{2.08} \] therefore \[ AC = 4.7 \times 10^{-14}(ht)^{0.81}/\text{C-H} \]
How To Make It Work

☐ Predictive:
  ± Assume a limit of 0.1 PAC in a facility with a 100 foot ceiling, this results in $2.2 \times 10^6$ 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
SSDIF Particle Counts
(Kanomax 3715 Particle Counters, 0.1 cfm)

- Hourly monitoring sums to $5.15 \times 10^5$ Class-Hours (>75% margin)
Ongoing monitoring at GSFC SSDIF

- Estimated AC/C-H (100 ft ceiling): $4.5 \times 10^{-10}$
- {Estimated AC/C-H (43 exchanges/hr): $5.9 \times 10^{-9}$}
- Measured AC/C-H (5μm channel): $4.9(±8.0) \times 10^{-10}$
- {Measured AC/C-H (0.5μm channel): $4.6(±9.2) \times 10^{-9}$}

Hamburg data: $9.3 \times 10^{-10}$ AC/C-H
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