THE ROLE OF SURFACE CLEANLINESS IN CONTAMINATION CONTROL

Koos Agricola agricola@brookhuis.com

Brookhuis Apllied Data Intelligence

cleanzone

Content

- Product contamination by particles
- Surface cleanliness
- ISO 14644-9:2022 surface cleanliness
- Contamination control
- Particle deposition rate
- ISO 14644-17:2021 PDR applications
- Resuspension rate
- ISO 14644-1:2015 air cleanliness
- Monitoring

cleanzone

Product contamination

- Product (and/or process) contamination is **surface contamination**
- A product analysis helps to determine the impact of particle (microbe carrying particle) contamination on its functionality
- The acceptable number and size of surface particles can be used to determine the **final surface cleanliness level SCL_{final}**
- The cleaning process before an assembly process determines the **initial surface cleanliness level $SCL_{initial}$**
- The difference between final and initial surface cleanliness determines the **particle contamination latitude =**

$$SCL_{final} - SCL_{initial}$$

Surface cleanliness

- Surface cleanliness is expressed as a number of particles ≥ D μm per m^2, dm^2 or cm^2
- Particle size D: equivalent diameter or diameter circumference circle around silhouette
- Measurement result N_D is expressed as cumulative number of particles per m^2
- Particle size distribution after exposure to environment: N_D = constant/D
- Surface Cleanliness Level: SCL = $N_1 = N_D \times D$

ISO 14644-9:2022 surface cleanliness

- Surface Cleanliness by Particle concentration: SCP
- SCL is the equivalent cumulative number of particles ≥ 1 µm per m^2
- In ISO 14644-9:2022 surface cleanliness levels are expressed $\log_{10}$ SCL

Selected SCP grading levels for cleanrooms and associated controlled environments

Units in particles per square metre

SCP level	Particle size								
	≥ 0,05 µm	≥ 0,1 µm	≥ 0,5 µm	≥ 1 µm	≥ 5 µm	≥ 10 µm	≥ 50 µm	≥ 100 µm	≥ 500 µm
SCP level 1	(200)	100	20	(10)					
SCP level 2	(2 000)	1 000	200	100	(20)	(10)			
SCP level 3	(20 000)	10 000	2 000	1 000	(200)	(100)			
SCP level 4	(200 000)	100 000	20 000	10 000	2 000	1 000	(200)	(100)	
SCP level 5		1 000 000	200 000	100 000	20 000	10 000	2 000	1 000	(200)
SCP level6		(10 000 000)	2 000 000	1 000 000	200 000	100 000	20 000	10 000	2 000
SCP level 7				10 000 000	2 000 000	1 000 000	200 000	100 000	20 000
SCP level 8						10 000 000	2 000 000	1 000 000	200 000

Contamination control

Product cleanliness strategy:

when to clean and to protect the product and where to control the environment

- Measures to prevent particle contamination of critical product surface(s) during exposure
  - Limiting exposure of critical product surface to environment
  - Limiting particle deposition rate by air cleanliness level and removal efficiency
  - Limiting introduction of particles (operation)
  - Limiting surface particles by cleaning
  - Monitoring air cleanliness, surface cleanliness
    and particle deposition rate

Particle deposition rate

- Particle Deposition Rate R_D is expressed by the number of particles ≥ D µm per m^2 per hour
- R_D = air cleanliness level (N_D /m^3) × deposition velocity of particles ≥ D µm in m/h
- R_D = change surface cleanliness in Ns_D/m^2 ÷ time of exposure in hours T
- Product contamination N_D by particles ≥ D µm = $R_D \times A \times T$
  - A = product area in m^2
- Increase of surface concentration during operation

$$SCL_T = SCL_{initial} + R_D \times D \times T$$

- High surface concentration can increase the particle deposition rate by resuspension

cleanzone

ISO 14644-17:2021 PDR applications

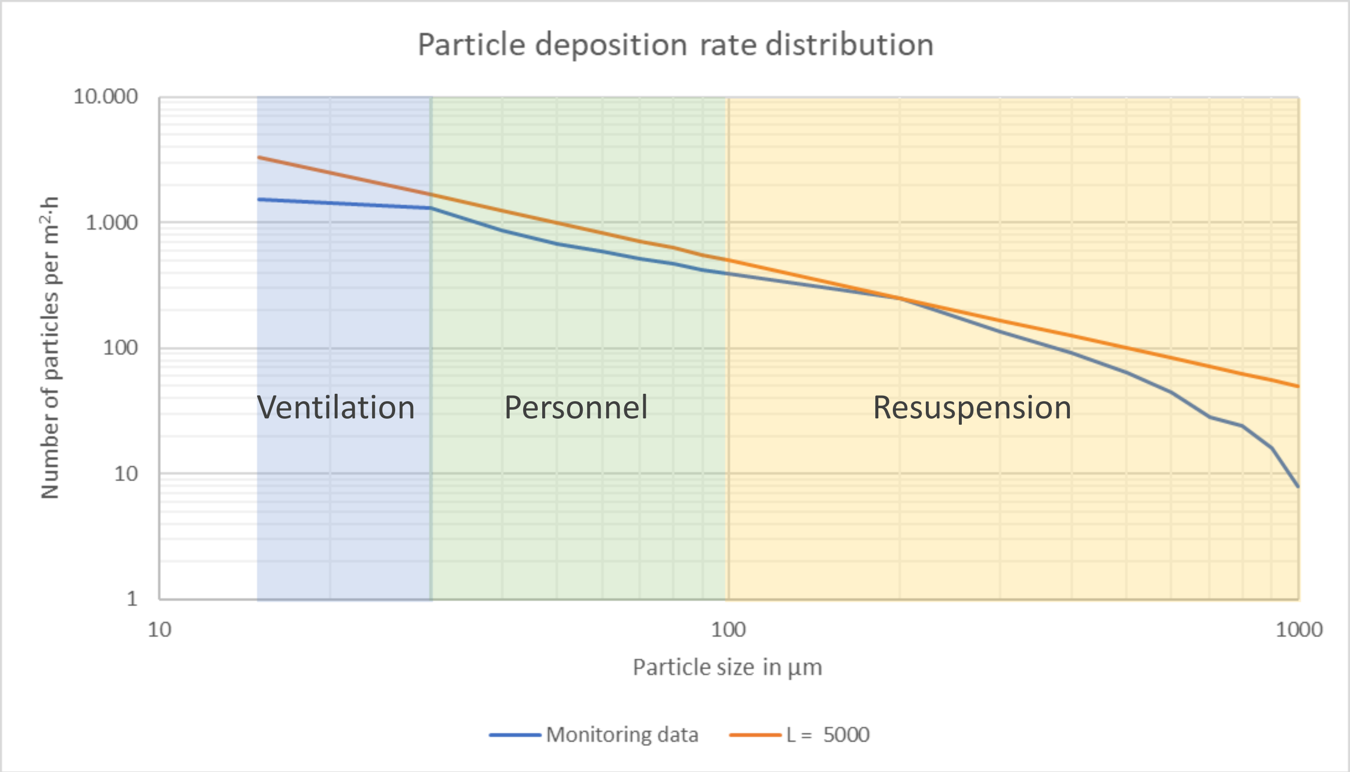
- Setting limits, establish and monitor control of deposition rate of macroparticles per $m^2 \cdot h$
- Particle deposition rate level L is equivalent number of particles ≥10 μm per $m^2 \cdot h$

$$L = R_D \times D/10$$

Particle deposition rate levels in orders of magnitude

Particle deposition rate level	Number of particles per m² per hour						
	≥5 μm	≥10 μm	≥20 μm	≥50 μm	≥100 μm	≥200 μm	≥500 μm
1	2,0	**1,0**	0,5	0,2	0,1	0,05	0,02
10	20	**10**	5	2	1	0,5	0,2
100	200	**100**	50	20	10	5	2
1 000	2 000	**1 000**	500	200	100	50	20
10 000	20 000	**10 000**	5 000	2 000	1 000	500	200
100 000	200 000	**100 000**	50 000	20 000	10 000	5 000	2 000
1 000 000	2 000 000	**1 000 000**	500 000	200 000	100 000	50 000	20 000

Cumulative particle size distribution of R_D



Resuspension rate

- Under influence of mechanical forces and turbulent airflows particles can be lifted from a surface into the boundary layer and then resuspend into the air
- The resuspension rate differs very much due to surface condition, humidity and removal forces
- The resuspension rate r is a fraction of the surface concentration

$$r = \frac{Sr_D}{Ns_D}$$

  - Sr_D is the number of emitted particles/h and Ns_D is the number of particles ≥ D µm/m^2
- For analysis in cleanrooms $r = 10^{-4}$ per m^2·h is suggested
- A particle resuspension rate level SrL can be introduced
  - $SrL = Sr_D \times D = r \times SCL$
- SrL depends on L and operational time after cleaning

cleanzone

ISO 14644-1:2015 air cleanliness

- Airborne particle concentration is determined by dilution of particle source strength $C = \frac{S}{\varepsilon \cdot Q}$
  - S is source strength (number of particles/s), Q is air supply (m^3/s) and ε is ventilation efficiency
- $C_{0.1}$ is cumulative concentration of particles ≥ 0.1 µm per m^3 measured by LSAPC
  - ISO Class is $\log_{10} C_{0.1}$

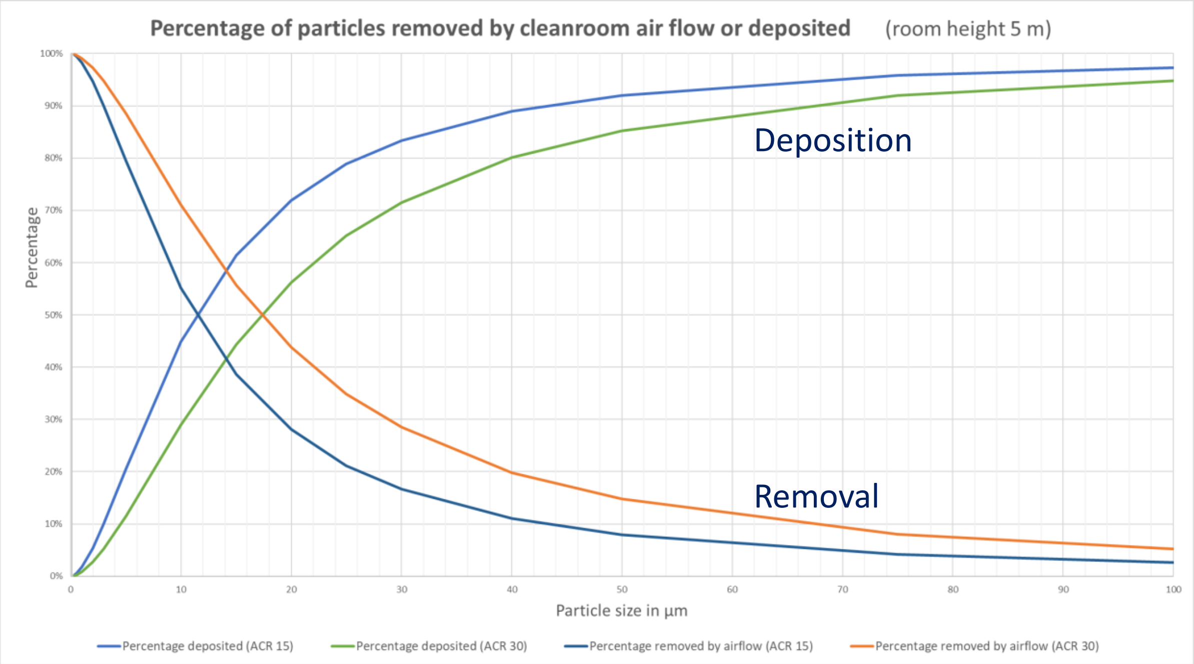
ISO Classes of air cleanliness by particle concentration

ISO Class number (*N*)	Maximum allowable concentrations (particles/m^3) for particles equal to and greater than the considered sizes, shown below[a]					
	0,1 µm	0,2 µm	0,3 µm	0,5 µm	1 µm	5 µm
1	*10*					
2	100	*24*	*10*			
3	1 000	237	102	*35*		
4	10 000	2 370	1 020	352	*83*	
5	100 000	23 700	10 200	3 520	832	
6	1 000 000	237 000	102 000	35 200	8 320	293
7				352 000	83 200	2 930
8				3 520 000	832 000	29 300
9				35 200 000	8 320 000	293 000

clea

Particle removal by ventilation

- Particle removal depends on effective air change rate and cleanroom height
- Effective air change rate: $\mathrm{ACR} = \frac{\varepsilon \cdot Q}{V}$ per hour
  - V is room volume in m^3



Surface cleanliness requirements

- The difference between final and initial surface cleanliness determines the contamination latitude
- Particle contamination occurs by deposition during exposure and contact transfer
- Particle deposition rate limit = Contamination Latitude/maximum time of exposure

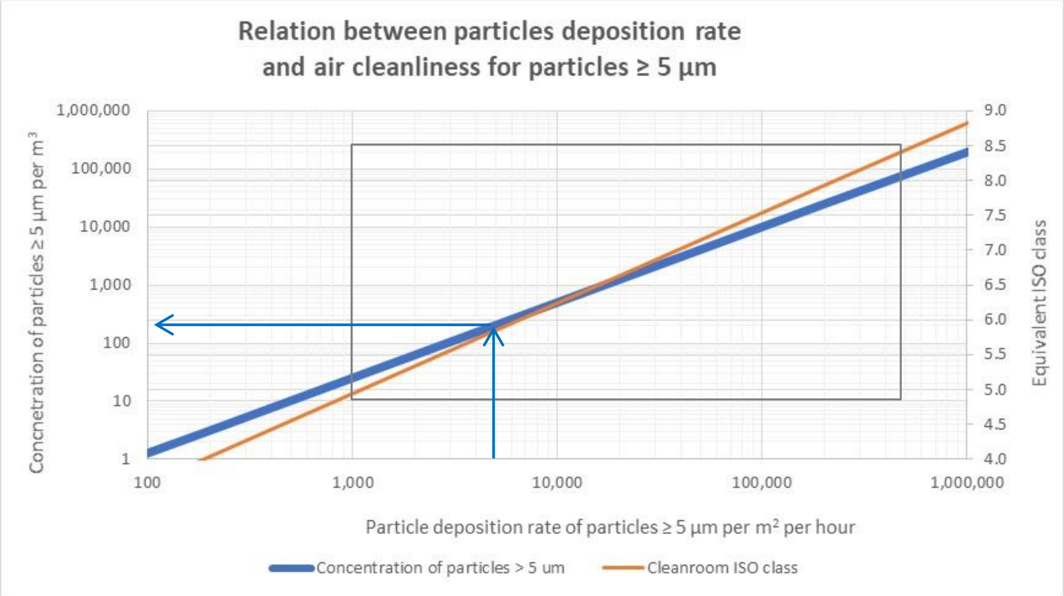
$$L \leq \frac{SCL_{final} - SCL_{initial}}{10 \ \times T}$$

- Leads to Air cleanliness limit (D < 40 µm) and requirements for operations
- Surface cleanliness limit ~ < 0.1 × (SCL_{final} – $SCL_{initial}$) ÷ number of contacts
  - Depends on transfer efficiency, here the average value 10 %

Relation air cleanliness and surface cleanliness

- Removal of airborne particles decreases rapidly with particle size for particles ≥ 5 µm
- Surface cleanliness changes by particle deposition rate
- $C_5 < R_5^{1.294}/295$ for $5 \leq D < 40$ µm
  - D ≥ 40 µm operational procedures

Example: L≤ 5.000 -> $C_5 \leq 208$ particles ≥ 5 µm ~ ISO 6



Cleaning frequency

- Determined by maximum surface cleanliness level SCL_{max} and particle deposition rate level L
    - SCL_{max} is determined by contact transfer and
    - the impact of resuspension rate level SrL
- $SCL = SCL_{after\ cleaning} + 10 \times L \times T$
- Surface cleanliness level after manual cleaning can be about 25.000 (ISO SCP 4.4) $\pm$ 50 %
- Time between cleanings: $T_{max} = \frac{SCL_{max} - SCL_{after\ cleaning}}{10 \times L}$
- Cleaning frequency = T_{max} ÷ operational hours per day

Monitoring surface cleanliness

- Measure surface cleanliness of various environmental surfaces
  - Trending, cleaning efficiency and particle deposition rate
- Next to measuring airborne concentration of particles
- Particle deposition rate level at critical locations

Map of cleanroom with surface measurement locations on the floor, tables and equipment.

New monitoring instruments

- SUMON is meant for monitoring cleanroom surfaces
  - counts and measures fluorescent particles > 20 µm
  - measurement area 10 cm^2
  - can collect 100 samples
  - gives trending,
  - calculates cleaning efficiency and
  - Particle Deposition Rate

New monitoring instruments

- Real time particle deposition monitor APMON II
    - Sample time 4 minutes
    - Measurement area 50 cm^2
    - Particles > 15 µm
    - Data access via AWS
    - INSIGHTS

cleanzone

Conclusion

- Traditionally focus on air cleanliness for particles ≥ 0.5 µm
- In cleanrooms with personnel the control of macroparticles is important
- Their removal by airflow decreases with particle size
- Deposition over time increases contact transfer and resuspension
- Monitoring particle deposition rate at critical locations demonstrates level of contamination control
- It shows the impact of discipline and surface cleanliness (resuspension of visible particles)
- Monitoring surface cleanliness provides information on the operational quality and effectiveness of the cleaning program

Thank you for your attention

HAVE YOU PUT YOUR DATA TO WORK?

www.brookhuis.com/cleanroom