A New Method for Experimental Studies in Cleanrooms – Particle Generation from Humans

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Summary

Particle generation from man is a severe problem when working in cleanrooms and other controlled environments. Data regarding the number of particles generated by man are few and there are not many detailed references to how these studies have been performed.

An experimental method to determine the particle release from a human being in a cleanroom was developed and used to describe the variation of particle concentration with time, in regards to both physical activity as well as the protective garment used. The particle strength of source for a human being was studied at different activities and wearing different types of clothing.

The results obtained could not be directly compared to data found in the literature, due to the lack of historical information. It was, however, found that the cleanroom garment used was much more efficient, when greater movements were performed by the test subject.

Introduction

Cleanrooms are highly specialized working areas used to protect product, process, as well as personnel from being contaminated. The air cleanliness in a cleanroom is controlled by introducing filtered ventilation air into the room and also by covering personnel in more or less specialized cleanroom garments to control particles released from the personnel. Cleanrooms are used in many different industries, for instance, in the microelectronics, the pharmaceutical industry as well as the food and beverage industry (1). Cleanroom technology is also used when performing certain orthopaedic surgical operations.

Ever since the first cleanrooms were developed during the 1950: s it has been known that people are the major and in many cases also the most critical sources of contaminants (i.e. dead particles as well as microorganisms). The particles generated by humans are to a very great extent skin scales that are released when the outer layer of skin is renewed. Furthermore, since all outer surfaces of our bodies are more or less covered with microorganisms, these are also released.

Solid contaminants generated by man can thus be divided into two major categories: dead particles and microorganisms. Both types of particles are mostly of great interest when protecting work undertaken in cleanrooms.

To counteract the particles generated from personnel in a cleanroom, specialized textile fabrics as well as types of garments are being used. Cleanroom garments are thus used in order to act as a filter and thereby as a barrier between the operator and the surrounding environment.

The number of particles emitted from a person during different activities and wearing different types of clothing can be found in the literature. Most of the information available originates from one source. In 1965 the "Austin contamination index" was published (2). This article states that a person wearing a smock on top of private clothes generates 100 000 particles per minute (≥ 0.3 μm) when sitting or standing totally still. At present, after more than 40 years, the "Austin contamination index", Table 1, is still used as a guideline. The total area of cleanroom technology including particle measuring methods has developed immensely since then. The data presented in the "Austin contamination index" are, as stated, "estimations of collected data". With this as background the natural question becomes: Does this really qualify as something that without any sign of doubt should or could be followed today?

Activity	Snap Smock	Membrane coverall	Ratio
Sitting or standing still	100 000	10	10 000
Light movement: head, leg, arm	500 000	50	10 000
Heavy movement: head, leg, arm, foot	1 000 000	100	10 000
Change position: Sitting down rising up	2 500 000	250	10 000
Walking 0.9 m/s	5 000 000	500	10 000
Walking 1.6 m/s	7 500 000	750	10 000
Walking 2.2 m/s	10 000 000	1 000	10 000

Table 1. “Austin’s contamination index”. Number of particles generated by a person per minute, at different degree of activity, wearing two different types of clothing (≥ 0.3μm). The ratio between snap smock and membrane coverall has been inserted by the author.

The purpose of this study was to develop an experimental method and establish a mathematical model to determining the particle strength of source of any particle generating object. This method was then used to study and determine the number of particles emitted from a person and, furthermore, to compare the data obtained with the data already existing in the literature. Different types of clothing and movement patterns were studied.

Method

Experimental set-up

The particle release from a human being was experimentally studied using a test chamber (3 x 3 x 2.4 m) with floor, ceiling and walls made of stainless steel. This cleanroom was entered trough a ventilated airlock equipped with airtight doors. The chamber was situated within a laboratory hall and equipped with a separate ventilation system, that was controlled in regards to temperature as well as relative air humidity. Furthermore, the air was filtered through an ULPA-filter, situated “point of use”. The relationship between the incoming and outgoing airflow produced an overpressure of at least 5 Pa. The temperature was 20°C and the humidity 35 % RH during all experiments performed. The particle size and concentration of airborne particles was measured using an aerodynamic particle sizer (APS, model 3321, TSI Inc., USA). The APS determines the particles' aerodynamic sizes, ranging between 0.3 and 20 µm.

Mathematical model

In order to calculate the strength of source, a model describing how the concentration varies with time and taking in account various parameters that affect the concentration, has to be established.

$$C = C_0 e^{-\frac{\alpha Q + v_d A}{V_r} \cdot t} + \frac{QC_I + c}{\alpha Q + v_d A}\left(1 - e^{-\frac{\alpha Q + v_d A}{V_r} \cdot t}\right) \qquad (1)$$

t	=	Time [s]
C	=	Particle concentration at time = t (particles/m^3)
C_0	=	Particle concentration when t = 0 (particles/m^3)
C_I	=	Particle concentration in the air into the chamber (particles/m^3)
Q	=	Ventilation flow rate (m^3/s)
v_d	=	Velocity of deposition (m/s)
A	=	Surface area of the chamber (m^2)
V_R	=	Volume of the chamber (m^3)
α	=	Mixing factor. For mixed ventilation the ideal value is 1, which means complete mixing
c	=	Strength of source, number of produced particles per time unit. (particles/s)

In order to determine the strength of source, all parameters and constants in Equation (1) have to be established. This was done using the following procedure. Equation (1) can be simplified by measuring the decay of particle concentration subsequent to the introduction of a portion of aerosols to the chamber. The time is set to zero, at an arbitrary point immediately after stopping the production of aerosol and the concentration at this time is C_0. Stopping the production of particles eliminates the strength of source and since the incoming air is filtered through an ULPA-filter the particle concentration, C_I , is almost equal to zero and thus eliminated from the equation. This simplified equation 1 to:

$$C = C_0 e^{-\frac{\alpha Q + v_d A}{V_r} \cdot t}$$

This expression can be brought to a linear form by taking the natural logarithm if it:

$$\ln C = \ln C_0 - \frac{\alpha Q + v_d A}{V_R} \cdot t$$

By plotting ln C as a function of time, the intersection with the y-axis, $\ln C_0$, and the slope

$$slope = \frac{\alpha Q + v_d A}{V_R}$$

could be determined. Since V_R is known, a value for $\alpha Q + v_d A$ can be calculated. This means that the only unknown parameter in Equation 1 becomes the strength of the source, c. The values of the unknown parameters as a function of the aerodynamic particle diameter was experimental determined using an aerosol generator (Palas BEG 100, Germany) with glass particles as solid aerosol.

Determining of the particle release from a person in a cleanroom

To determine the strength of source, the test person entered the cleanroom trough the airtight airlock. Inside the cleanroom the person performed specified movement patterns and the particle concentration was measured during a period of 30 - 45 minutes. The measured time-dependent particle concentration was fitted using a statistical software (Microcal Origin 5.0, Microcal Software Inc., USA) using Equation 1. The characteristic constants for the different particle size intervals, determined in earlier experiments, were inserted and the unknown strength of source was determined, using the least-square method.

Different people generate different amounts of particles at different times depending on various parameters. In order to perform a reliable and exact investigation all tests must be performed in a very controlled manner. The test person has to follow exactly the same every-day procedures before and in between experiments and must not be exposed to environments containing elevated levels of particulate matter. To assure the reliability of the experiments a reference method was used.

First, in a series of experiment during one day, where the test person was wearing underpants only and not performing any movement, the strength of source was determined seven times subsequently, Figure 1. During this study it was observed that a stable particle release after showering was obtained first after approximately 6 hours. For that reason, the test person followed a standardized procedure every day and all experiments were performed at least 6.5 hours after showering.

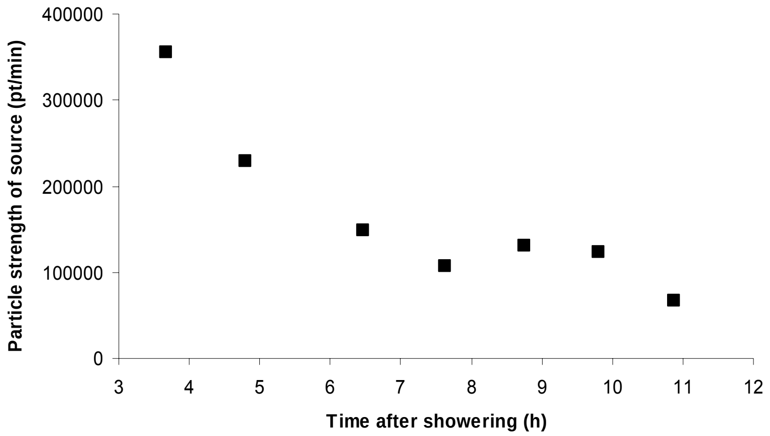


Figure 1. Particle strength of source as a function of time after showering ($D_a \geq 0.53$ µm)

During several days a number of reference experiments were performed in which the test person was wearing the same clothes and performing the same activity. This was used to establish a reference level. All experimental days started off with a reference test after which a ratio to the reference level was determined to make the different tests directly compared.

Characteristics of the test person and movement patterns

The test person: Male, weighing 68 kg and 176 cm tall, with moderate hair length and no facial hair.

Cleanroom garment: Coverall and hood (100 % polyester), single use facial protection and latex gloves. The coverall and hood, was produced in a cleanroom environment and was new and not subjected to washing prior to use.

Movement:
Sitting totally still - No movement at all.

Sitting while performing arm movements - One arm, at a time was moved with an angle of 90°, back and forth in a sweeping action. The original position of the arm should be directed straight ahead with a 90° bend at the elbow. The movement frequency was one second for one arm to be moved back and forth.

Standing with rotating torso - Both hands grabbing the waist and rotating the upper body from side to side, as far as possible in each direction. The time for turning from one side to the other was one second.

Walking on the spot - Walking on the spot with a frequency of two steps per second.

Figure 2 shows the particle concentration increasing after the test person has entered the test chamber. After about the 30 - 45 minutes the particle concentration is stabilized. The mean particles size distribution at this steady state condition is shown in Figure 3.

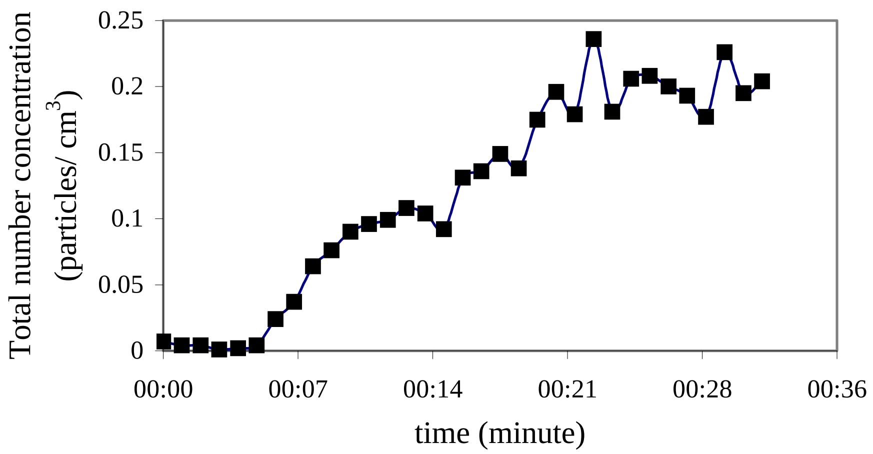
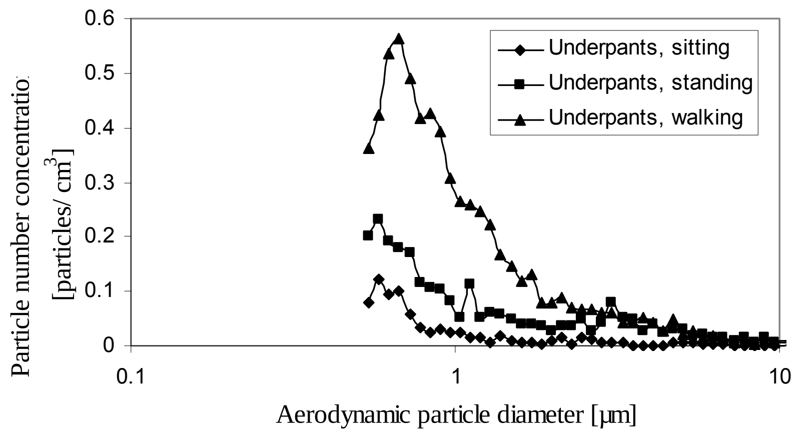


Figure 2. Variation of particle concentration versus time with a test person wearing underpants only and walking on the spot.



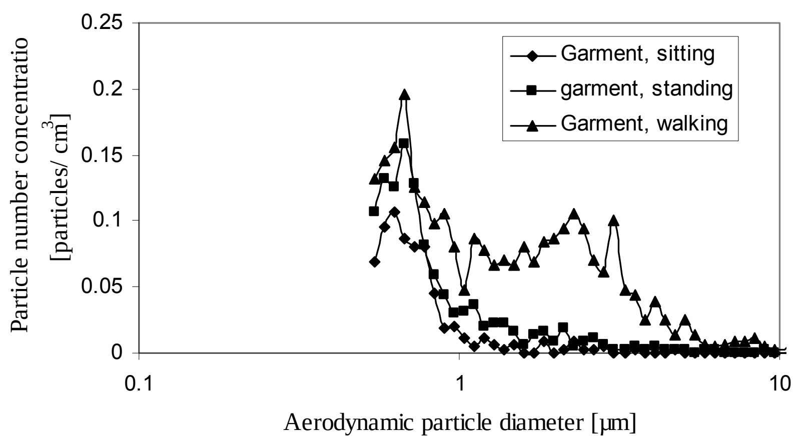


Figure 3. Particle concentration versus aerodynamic particle diameter for a test person wearing underpants only and cleanroom garment, performing different movements.

The estimated particle strength of source for different clothing and activity of the test person is summarized in Table 2.

Table 2. Particle strength of source for the test person performing various physical activities and wearing underpants and cleanroom garment, respectively. ($D_a \geq 0.53$ µm). The ratio of underpants and cleanroom garment has been inserted.

Activity	Underpants (particles/min)	Cleanroom garment (particles/min)	Ratio
Sitting still	40 000	40 000	1
Sitting - arm movements	90 000	70 000	1.3
Standing - rotation torso	140 000	60 000	2
Walking on the spot	400 000	180 000	2.2

Conclusions

The number of particles generated by a human being presented in this paper cannot be directly compared to the data obtained from the "Austin contamination index", since these data only applies for particles ≥ 0,3 µm and the test method is not fully described in the literature. The data obtained during these investigations are valid for particle sizes between 0.53 and 10 µm measured as equivalent aerodynamic particle diameter. Our results can not be considered as general since only one person has been tested. However, a method that can be used to study the efficiency of protective garment in cleanroom has been developed. Further studies are now in progress at our laboratory in Lund.

Acknowledgement

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References

1. M. Ramstorp (2000) "Introduction to contamination control and cleanroom technology" WILEY-VCH Verlag GmbH, Weinheim, (Germany), 168 pages
2. P. R. Austin and S. W. Timmerman (1965) "Design and operation of clean rooms", Business New Publishing Co, Detroit (USA) pp 235 - 251