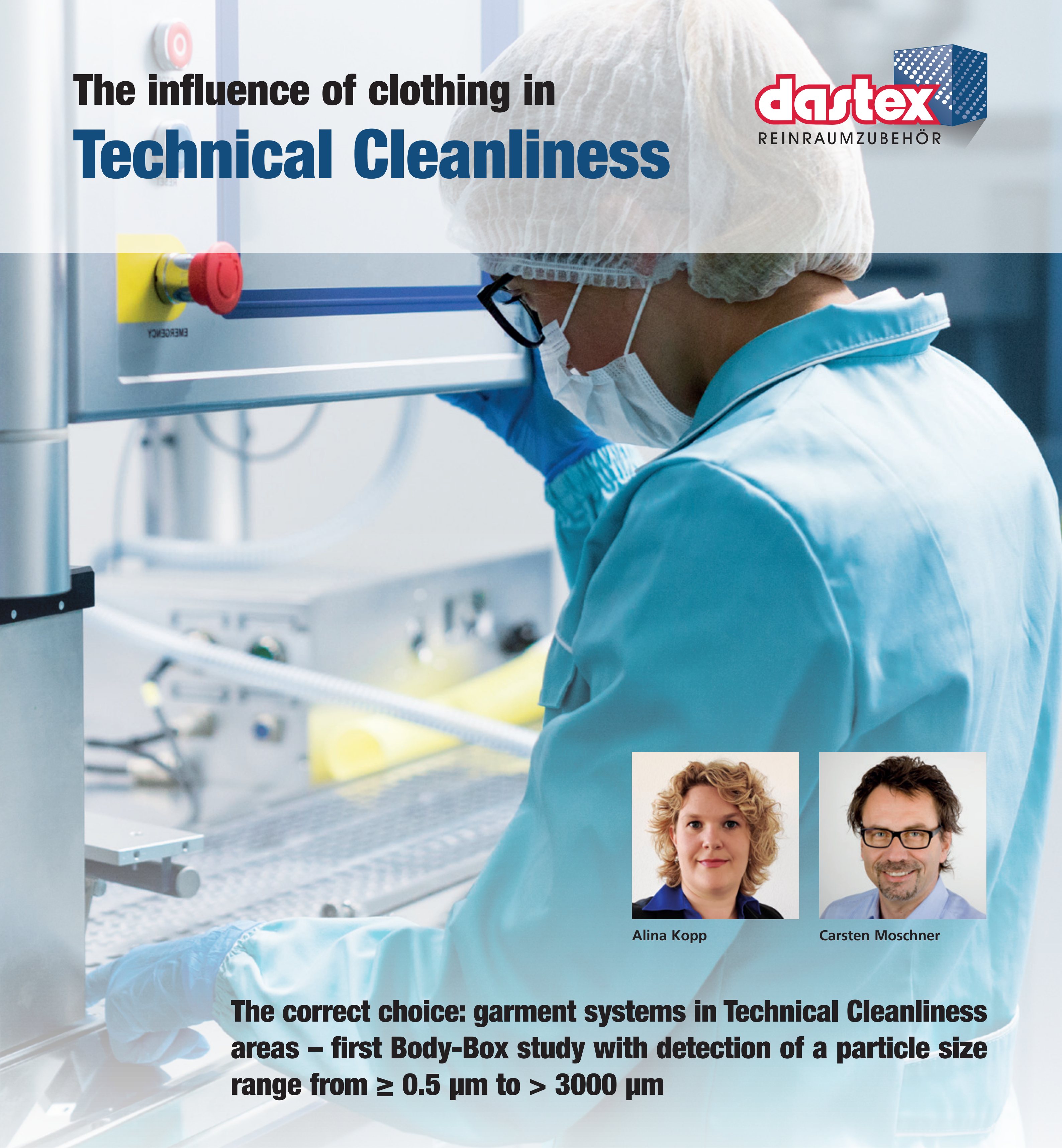

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REINRAUMZUBEHÖR

The influence of clothing in Technical Cleanliness

Alina Kopp

Carsten Moschner

The correct choice: garment systems in Technical Cleanliness areas – first Body-Box study with detection of a particle size range from ≥ 0.5 µm to > 3000 µm

In cleanroom areas, humans play a major role as a source of contamination [8]. Their impact should also not be underestimated in the cleanliness areas of the automotive industries [11]: Employees can bring in contaminants, which are critical, and in some cases functional or safety-relevant not only for production, but also for the final product.

In both cleanroom and cleanliness areas, a correctly selected garment system, complementary to the process and its specifications, contributes significantly to avoidance of such contamination. Until now, there has been neither a measurement methodology nor data on this.

Body-Box studies have been carried out in Dastex's in-house Research and Development department since 2004 [6]. These are carried out for internal questions or at the request of customers, so far on topics such as disposable vs. reusable garments [7], cleanroom undergarments, germ measurements [9] and ageing studies [10]. Here focus has been on a particle size spectrum of ≥ 0.5 µm to ≥ 10 µm (according to DIN EN ISO 14644) and, in some studies, on recording the bacterial count using BioTrak® Real-Time Viable Particle Counter and other (according to Good Manufacturing Practice (GMP) guidelines). The method now introduced in cooperation with CleanControlling GmbH extends the particle size range upwards to a particle size of ≥ 3000 µm and thus closes a research gap (see Figure 1). The Body-Box measurement method for the area of technical cleanliness according to VDA 19 was successfully established in an initial study. The results clearly show which cleanroom garment systems should be used in the area of Technical Cleanliness.

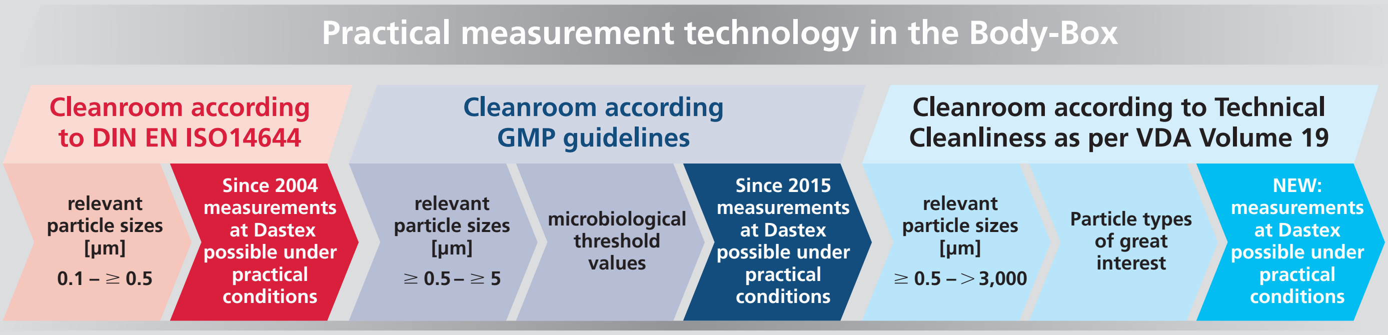


Figure 1: Practical measurement methodology in the Body-Box: The garment system, which is adapted to individual requirements, can now be examined under practical conditions for all areas.

Presentation of the new method

The new method is introduced below. It is based on the Body-Box measurement method, which refers to on IEST-RP-CC003.4 and was implemented at Dastex 2004 [6]. This method is currently the only measurement procedure by means of which cleanroom garment systems can be tested under practical conditions. In a clean area with dimensions of approx. 1.20 x 1.20 x 2.40 m, a test person performs defined movement sequences with the garment system to be tested. The particles generated in the process are detected by optical particle counters (OPC) and evaluated accordingly.

Selection of the appropriate particle measurement method:

The detection of particles by optical particle counters is only reliable and applicable up to a certain particle size. Reasons for this include:

- Various physical properties. Gravity influences, for example, can lead to sedimentation with particles ≥ 5 µm [3]. This effect increases noticeably with increasing pipe length or particle diameter, among other things. Furthermore, particle losses can occur due to inertial forces and turbulence [3]. Particles > 100 µm would sediment on the way to the OPC and are not included in the counting result.
- In addition, it is not possible to detect such large particles using diffused light measurement technology. The devices available on the market can be used up to a maximum particle size of 500 µm (air particle counter Abakus® mobil air LDS 2/2; 5 – 500 µm by Markus Klotz GmbH [5]), if the particles arrive in the measuring chamber despite the influences described above. In the devices from Mr Klotz, for example, the measuring chamber is arranged directly after the sampling probe. This means that the particles do not have to pass through a long sampling tube first, but are guided into the measuring chamber in the most direct way.
- Optical particle counters are generally calibrated with monodisperse polystyrene latex (PSL) particles. PSL particles are ideally round. „I.e. all counts and particle sizes measured with such a calibrated instrument are all related to the diameter of PSL particles." [3]. However, this does not correspond to the natural shape and occurrence of particles. Particles above a certain size in particular can have significantly different length and width expansions. The optical particle counter then detects the particles according to their orientation and incidence of light and not according to their actual size.

In the automotive industry, the longest expansion ($Feret_{max}$) of a particle is also used to define the „worst case damage potential" [12]. Therefore, the correct measurement of particles > 100 µm is very important.

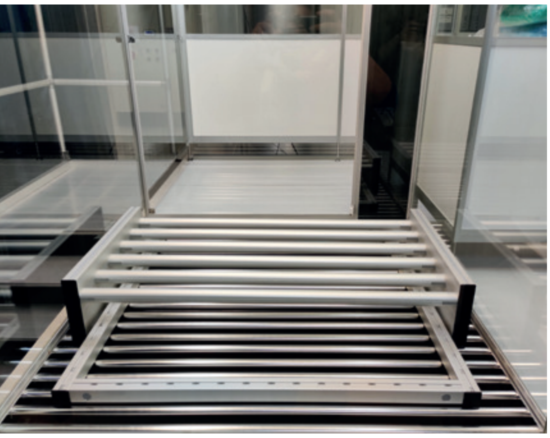


Figure 2a: Experimental setup; frame and step grid in Body-Box

Figure 2b: Mounting analysis filter cloth

Figure 2c: Test person performs the movement sequence over the analysis filter cloth

Measurement with an optical particle counter is therefore unsuitable for the detection of particles up to ≥ 3000 µm for the measurement setup.

For the measurements using optical particle counters in the Body-Box, the airflow was „designed to ensure representative sampling“ [6]. However, this is only the case for the detection of small particles. Reasons for this (physical properties) have already been explained elsewhere. When measuring the smaller particles using OPC, it is therefore sufficient to measure only a partial flow and then extrapolate the number accordingly to the total volume. Due to the natural size distribution of particles, a significantly lower number of large particles is expected. Moreover, the large particles will not be homogeneously distributed in the air flow. Therefore, an examination of a partial flow is not considered sufficient and the total amount of air flow is filtered, collected and evaluated. To prevent particle loss as far as possible, the particle filtration is placed close to and directly below the particle generation. In order to take into account the Technical Cleanliness requirements of the automotive industry, the analysis procedure consisting of particle extraction from the filter cloth and the evaluation is based on the standard of VDA19 Part 1.

New test method integrated in the Body-Box

After careful reflection on various concepts, one approach was finally further refined and implemented. As shown in figure 2a, a frame was integrated into the Body-Box. A defined analysis cloth is mounted into this frame under the highest purity requirements (Figure 2b). This cloth acts as a collection filter for the particles emitted by the test person/garment system. It is designed in such a way that the air flow is only slightly influenced and at the same time particles ≥ 15 µm are safely retained. The test person performs the required movements on a step grid arranged above the analysis garment (Figure 2c). The test procedure is identical to all other studies. The test person enters the Body-Box and first stands for five minutes, then walks on the spot for five minutes. The procedure is repeated and concluded with a five-minute standing phase. A differentiated analysis of the walking and standing phases is not possible with this test procedure. However, the test procedure could be adapted for this purpose. In order to prevent particles from being lost when they are removed from the analysis cloth, a previously determined folding technique is used when unclamping. This is followed by packaging in a clean bag. After univocal labelling, the sample is sent to CleanControlling.

After gentle courier transport of the filter cloth to the Technical Cleanliness laboratory of CleanControlling, the test piece is fed into the ISO Class 6 cleanroom via the material airlock and prepared for extraction. For particle extraction of the unfolded analysis filter cloth, a correspondingly large extraction chamber is used, which is commonly used in the automotive industry for truck crankcases. The extraction chamber has a defined and known cleanliness status via the blank value measurement. The blank value is evaluated according to VDA19 Part 1 specifications. The filter cloth is hung transversely in the chamber and sprayed on both sides with 20 l of cold cleaner each at a defined liquid volume flow. The test liquid is led via a collecting funnel to the filter point, in which a mesh filter with a mesh size of 1 µm is inserted.

	Number of runs	Other worn garments
Streetwear (cotton)	10	disposable caps, pair of cleanroom socks, pair of cleanroom shoes
Streetwear (cotton) + Lab coat (new) ION-NOSTAT VI.2	10	
Streetwear (cotton) + Lab coat (60x) ION-NOSTAT VI.2	10	
Cleanroom undergarments + Lab coat (new) ION-NOSTAT VI.2	5	
Streetwear (cotton) + Overall (new) ION-NOSTAT LS Light 125.2	10	
Streetwear (cotton) + Overall (60x) ION-NOSTAT LS Light 125.2	10	

Table 1: Overview of tested garment systems

The filtration is supported by means of a vacuum. After a rinsing procedure of the chamber, the filter can be handed over for microscopic evaluation.

The microscopic evaluation of the particles on the analysis filter is carried out on a stereo light microscope system with automatic XY-table and particle counting software from JOMESA. This system was parameterised as specified in the standard evaluation according to VDA19 Part 1. The focus is on particles > 50 µm and the measurement of the particle length according to Feretmax in order to be able to measure the largest expansion of the particles. Metallic and non-metallic particles are counted and measured via a polarisation filter, but fibres are also included via a length/width factor.

When focusing on the large particles, they are manually checked microscopically by the operator via the live image and edited if necessary. Subsequently, the largest particles are recorded pictorially in the protocol.

The protocol with all analysis results is sent to Dastex for further evaluation.

First study with the newly integrated measurement method:

The first study was a comparative study of different garment concepts. In addition, for two of the garment systems, a comparison was made between new outerwear and 60 times decontaminated outerwear.

As can be seen from Table 1, the lab coat was made of the garment fabric ION-NOSTAT VI.2. This cleanroom fabric is „one of the most balanced and high-quality cleanroom textiles currently available on the market. In addition to its very good filtration efficiency, ION-NOSTAT VI.2 is distinguished in particular by its exceptionally good wearing comfort properties. These include first and foremost water-vapour permeability (breathability) and haptics, i.e. the feel of the textile. These properties are supplemented by very good antistatic values, so that ION-NOSTAT VI.2 can also be used in ESD areas at any time. Added to this is its high abrasion resistance or rather low roughening disposition." [1]

The cleanroom garment fabric ION-NOSTAT LS Light 125.2 was used for the coverall, which „is on the one hand a compromise between the typical requirements of a cleanroom fabric in terms of filtration efficiency, abrasion resistance and intrinsic particle emission, and on the other hand the highest possible level of wearer comfort, i.e. breathability and pleasant haptics (feel). The values in the conductivity range are satisfactory. The filtration efficiency and abrasion resistance (roughening disposition) correspond to the typical requirements of the actual application area, i.e. the requirements of an ISO 8/ ISO 9 environment (ISO 14644-1) or hygiene zones D and E." [2]

A cleanroom fabric was deliberately chosen for the lab coat, which is recommended for use in air cleanliness classes EN ISO 14644-1 4 and worse, and a cleanroom fabric for classes 8+9 for the overall. This is to show how an overall with a higher wearing comfort behaves in comparison to a lab coat with a higher filtration efficiency. Ergo, what influence the cut shape can have on cleanliness. The study will also show how cleanroom undergarments under a lab coat have an impact on the risk of contamination when worn under a cleanroom garment instead of a streetwear.

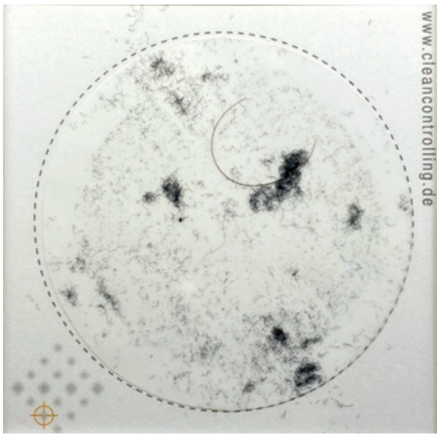
Experimental procedure:

Test preparation:

As in all Body-Box studies, the Body-Box is switched on in preparation and operated empty so that an ISO Class 4 is achieved. This is monitored by the optical particle counters running in parallel. Before the test is carried out, the Body-Box – including the test equipment – is cleaned with 70/30 isopropanol cleanroom cleaning wipes while wearing cleanroom garments. Gloves are then changed before the analysis cloth is mounted with low contamination (Figure 2b).

Reference measurements:

Since residual contamination on the analysis cloth after decontamination cannot be excluded and it must also be assumed that contamination occurs during the clamping and unclamping procedure, three analysis



Streetwear (cotton)

cloth are clamped per production and decontamination batch and unclamped again after five minutes. The procedure is identical to all other measurements. The evaluation of the analysis cloth is regarded as a reference value of the respective measurement series and subtracted from the measured values.

Experimental procedure:

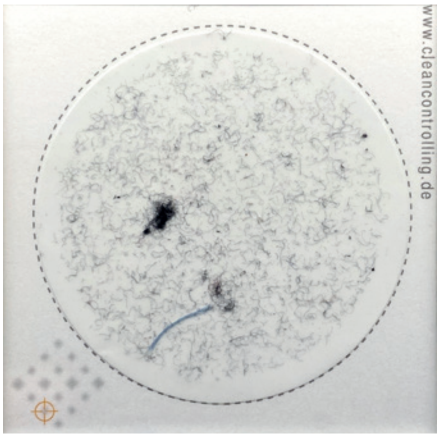
The test person dresses in the appropriate garment system and then enters the Body-Box. There he or she performs the prescribed sequence of movements: standing for five minutes, walking for five minutes, standing for five minutes, walking for five minutes and standing again for five minutes. Afterwards, the test person leaves the Body-Box.

Test post-processing:

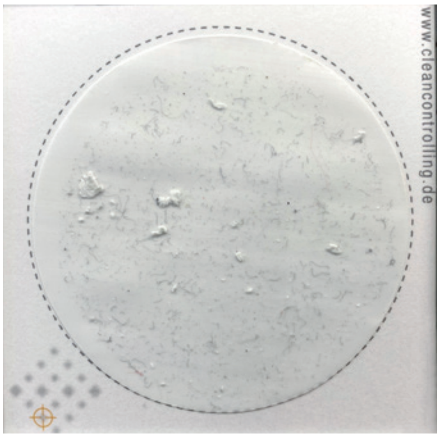
In full cleanroom garments, the analysis cloth is stretched and folded according to a previously defined procedure to ensure that no particles are lost. The cloth is packed in a cleanroom bag, univocally labelled and sent to CleanControlling for extraction and evaluation.

Measurement methodology and evaluation:

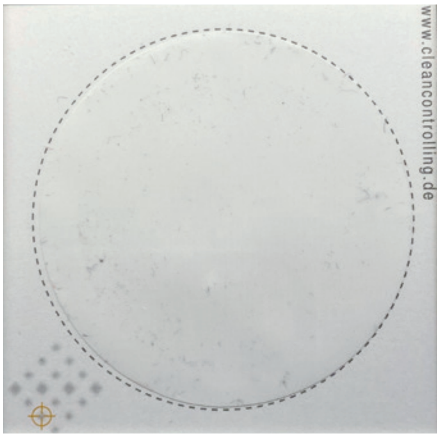
The filter cloth is hung transversely in the extraction chamber located in the clean room (ISO class 6) and sprayed on both sides with 20 l of cold cleaner each and a defined liquid volume flow. The test liquid is filtered through an analysis filter (mesh size 1 µm). After a rinsing procedure of the chamber, the analysis filter is removed and evaluated microscopically. The evaluation is carried out with a stereo light microscope system with



Streetwear (cotton)
+ Lab coat (new) ION-NOSTAT VI.2



Streetwear (cotton)
+ Overall (new) ION-NOSTAT LS Light 125.2



Cleanroom undergarments
+ Lab coat (new) ION-NOSTAT VI.2

automatic XY-table and the particle counting software from JOMESA. This system was parametrised as specified in the standard evaluation according to VDA19 Part 1. The focus is on particles > 50 µm and the measurement of the particle length according to Feretmax in order to be able to measure the largest expansion of the particles. Metallic and non-metallic particles are counted and measured via a polarisation filter, but fibres are also included via a length/width factor. When focussing on the large particles, these are manually checked microscopically by the operator via the live image and edited if necessary. Subsequently, the largest particles are recorded as pictures in the protocol. The protocol with all analysis results was sent to Dastex for further evaluation.

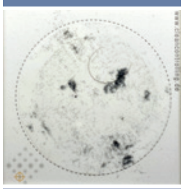
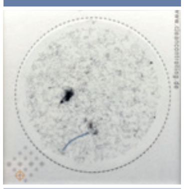
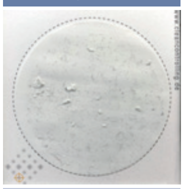
	Streetwear (cotton)	Streetwear (cotton) + Lab coat (new) ION-NOSTAT VI.2	Streetwear (cotton) + Overall (new) ION-NOSTAT LS Light 125.2	Cleanroom undergarments + Lab coat (new) ION-NOSTAT VI.2
Filter assignment				
Particle sizes [µm]	[particles/minute]	[particles/minute]	[particles/minute]	[particles/minute]
≥ 0.5 – < 1	6,224,516	2,766,404	787,075	1,034,514
≥ 1 – < 5	3,317,365	765,072	265,946	146,072
≥ 5 – < 10	114,665	20,065	5,125	951
≥ 10	23,826	3,998	1,325	102
≥ 15 – < 100	152	286	87	39
≥ 100 – < 400	139	108	40	6
≥ 400 – < 1,500	54	49	8	0
≥ 1,500	5	8	1	0
Total ≥ 0.5 – > 3,000	9,680,723	3,555,990	1,059,605	1,181,685
Particle reduction through respective garment system compared to streetwear ≥ 0.5 – > 3,000		63%	89%	88%
Total ≥ 100 – > 1,500	198	165	48	6
Particle reduction through respective garment system compared to streetwear ≥ 100 – > 1,500		17%	71%	88%
Total ≥ 400 – > 1,500	59	57	9	0
Particle reduction through respective garment system compared to streetwear ≥ 400 – > 1,500		4%	85%	99%

Table 2: Results as a comparative representation of the different garment systems

Processing of the results:

For the entire study, comparable to all other studies, an optical particle counter is used in parallel for the detection of particles from ≥ 0.5 µm – ≥ 10 µm. For the evaluation and presentation of the results, the particle counts from the extraction procedure and microscopic evaluation as well as the optical particle counters are uniformly converted to particles per minute.

A detailed presentation of the particle types is not made in the results of this study, as metallic particles are not to be expected in this test setup. However, this is very conceivable in future commissioned studies when already worn garments are tested.

Results and discussion:

Table 2 shows an overview of the detected particle counts. The particle size channels ≥ 0.5 – ≥ 10 µm were detected with the optical particle counter.
The ranges 15 – > 1,500 µm were evaluated by extraction and light optical method.

The retained materials on the analysis filter shows very clearly the result, which can be substantiated with figures: Simply wearing a lab coat over streetwear is not enough. Although this achieves a reduction of 63% when considering the entire particle size range, the large particles still simply fall out of the bottom of the lab coat. This explains the improvement of just 4 – 17% in the particle size ranges > 100 µm and > 400 µm.

If the streetwear is replaced by a cleanroom underwear, a significantly higher reduction

	Streetwear (cotton) + Lab coat (new) ION-NOSTAT VI.2	Streetwear (cotton) + Lab coat (60x) ION-NOSTAT VI.2	Streetwear (cotton) + Overall (new) ION-NOSTAT LS Light 125.2	Streetwear (cotton) + Overall (60x) ION-NOSTAT LS Light 125.2
Particle size [µm]	particles/minute]	particles/minute]	particles/minute]	particles/minute]
≥ 0,5 – < 1	2,766,404	2,151,290	787,075	611,744
≥ 1 – < 5	765,072	708,827	265,946	72,113
≥ 5 – < 10	20,065	19,530	5,125	404
≥ 10	3,998	3,771	1,325	98
≥ 15 – < 100	286	199	87	26
≥ 100 – < 400	108	74	40	11
≥ 400 – < 1,500	49	28	8	4
≥ 1,500	8	4	1	1
Total ≥ 0.5 – > 3,000	3,555,990	2,883,724	1,059,605	684,402

Table 3: Results with focus on ageing differences

of up to 99% is achieved. A similarly good reduction in particle counts is achieved when an overall made of ION-NOSTAT LS Light 125.2 is worn over the streetwear. With this very low number of particles, no statement can be made about which of the two garment systems is „better". They both show very good results, which of the two should be used in the respective production depends on further factors, which will not be discussed in more detail here.

The images of the material on the filter also show that the particular challenge in microscopic analysis and post-control was to edit the many fibrous particles, some of which were intertwined, in such a way that the counting result could be used in the study for reliable cleanliness comparisons.

Table 3 compares the particle counts of the respective new condition (new) and age-simulated condition (60x). The results show that the fabrics retain the majority of the particles after the 60 decontamination cycles just as in the new condition, in some cases even more.

As the garment system ranking (Figure 3) illustrates, with 0 – 6 particles/minute (depending on the particle size range), the least particles were detected when using a lab coat made of ION-NOSTAT VI.2 in combination with a cleanroom undergarment. This is closely followed by the values of the ION-NOSTAT LS Light 125.2 overall with 5 – 48 particles/minute (depending on the particle size range). At the same time, the textile is very comfortable to wear. As expected, the streetwear emits the most particles with 59 or 198 particles/minute. It should be mentioned here that this is a freshly washed cotton jogging suit that was only worn in the Body-Box. With normal streetwear, a significantly higher particulate contamination is to be expected. Here, street dirt, contamination from pets, for example, and many others are added. All these particles fall out of the lab coat at the bottom, which is why the particle values of the streetwear + lab coat are high at approx. 32 – 165 particles/minute despite the high-quality cleanroom textile ION-NOSTAT VI.2. Contaminants that fall down do not automatically sediment on the floor and certainly do not remain there immobile. Depending on the type of particle, particles remain suspended in the air for a long time. Due to movements (walking movements of staff, airflows, etc.) the particles are stirred up with the airflows and can settle on the work areas and thus on the products. Therefore it is not recommended to choose the streetwear + lab coat variant above a certain required level of cleanliness.

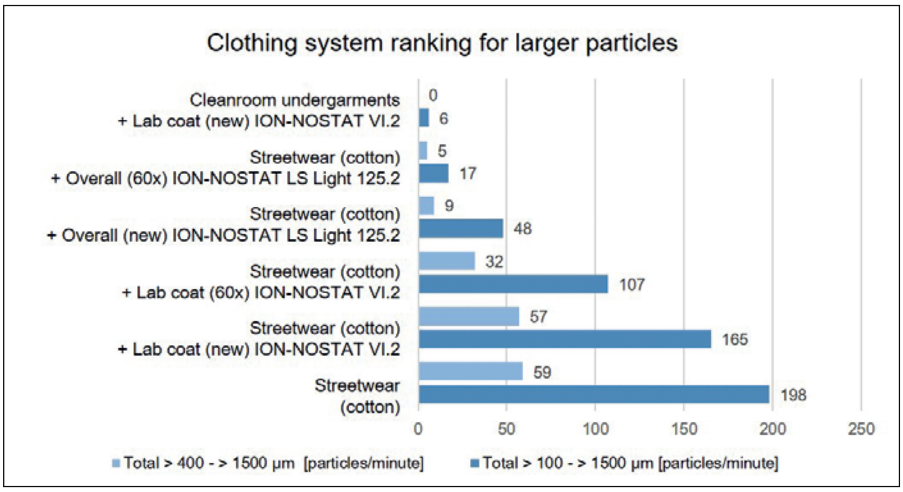


Figure 3: Garment system ranking

Conclusion and Outlook

The results from the first study clearly show which garment systems should be chosen for which areas. It also shows what influence the fabric and the cut shape have on cleanliness. Depending on how the individual requirements were specified, different garment systems can reduce the source of contamination in the cleanroom.

The introduced measurement method closes the previous gap and thus enables the practical determination of particle values up to a size of ≥ 3,000 µm. The measurement method used not only results in a quantitative evaluation, but a breakdown into the individual particle types can also be carried out if required and appropriate. If a user decides to conduct a study with clothing already worn in production, conclusions could be drawn about the removal of metallic particles through decontamination. It is quite conceivable that metallic particles adhere to the fibres and are only removed by the movement of the employee.
Such a study could be used, for example, to define maximum wearing cycles or, if necessary, to optimise the garment system in the more stressed areas.

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Authors

Alina Kopp, Carsten Moschner
Dastex Reinraumzubehör

Yasemin Müller, Volker Burger
CleanControlling GmbH
Emmingen-Liptingen
Tel.: +49 7465 929 678 0
info@cleancontrolling.de
www.cleancontrolling.de

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REINRAUMZUBEHÖR

Dastex Reinraumzubehör GmbH & Co. KG
Draisstr. 23
76461 Muggensturm
GERMANY
Telephone +49 7222 9696-60
Telefax +49 7222 9696-88
E-mail info@dastex.com

www.dastex.com

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