Human source of contamination

Man-made particulate emissions

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In the discussion on the topic of „Human source of contamination“, the following question is generally at the centre of attention: „How many particles does a human emit on average per minute?
This question is of course supplemented by the particle sizes of interest in each case. In addition, this question must be supplemented with regard to the intensity of human movement, because it is easy to understand that a person standing still probably emits considerably fewer particles than a person who moves around a lot.

On the subject of „germ contamination“ released by humans, there are quite precise statements in various sources. On the subject of „How many particles does a person generate under which conditions?“, however, very few statements can be found in the specialist literature and these appear – on closer inspection – to be very vague. In this context, information from P. R. Austin is often used, which was determined around 1970 [1]. Unfortunately there are no recent studies on this topic. Nor to the also very interesting question „How do the particle numbers of an employee behave when he wears only a lab coat, for example, compared to when he wears an coverall?“

Dastex has taken this as an opportunity to carry out a major study on the subject over an extended period of time.

Study setup and influencing variables

The Body-Box test cabin set up on the company's own premises formed the metrological basis for this. The principle of measurement within a Body-Box is described in the IEST Recommendation Practice [2]. A defined cleanroom (with a floor area of 1.20 x 1.20 m) is completely covered with a Filter Fan Unit (H14 filter) and the floor construction is

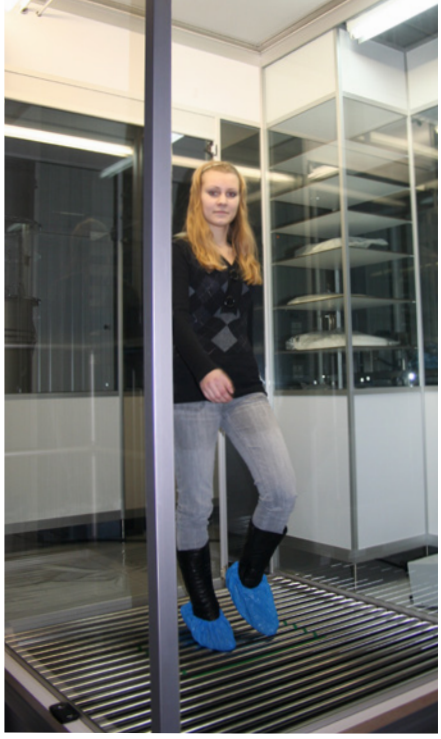

Fig. 1: Test person in street clothes during the walking simulation in the Body-Box

Fig.2: Test person in cleanroom lab coat and suitable accessories during the standing simulation in the Body-Box

Fig. 3: Test person in cleanroom coverall and suitable accessories during the standing simulation in the Body-Box

designed so that the air can be fed into the return air ventiduct with as little turbulence as possible. In the Body-Box itself there are constant conditions in terms of temperature and humidity and in relation to the air speed (air exchange) set for the respective series of measurements and the cleanliness level when in idle mode (= without the test person being in the Body-Box). When the air treatment is running, the air cleanliness class ISO 4 (according to ISO 14644-1) can be maintained without any problems in the Body-Box when idling.

If a person enters the Body-Box, almost all the measured particles are therefore deriving from this person and his/her clothing. Measurements in the return air ventiduct are carried out on defined measuring points and it must be taken into account that the sample volume flow must of course be set in the correct ratio to the total volume flow. Much more clean air is supplied to the test cabin via the FFU than can be extracted again via the measuring probes placed in the return air ventiduct. This results in a multiplication factor of the measured values as a function of the air flow set in each case.

In addition, a large number of other factors must be taken into account in such measurements. It is easy to understand that people do not emit an even number of particles over the course of the day. Even the private „street clothes" worn can vary greatly in their particle emission. The intensity of movement during the study has a corresponding influence, etc. For comparative studies it is therefore essential to keep as many of these influencing factors as possible constant or to define them accordingly in advance. Due to our experience of several years with this test cabin, we were able to narrow down the most important of these influencing factors accordingly. In the following, the different test series are presented in more detail.

Particle emission during movement in street clothes

The first series of tests dealt with the question already posed at the beginning: How many particles does a person emit depending on the degree of movement without any garment element being defined in advance in these test series. This means that the test persons could wear their normal street clothes for the tests. Several test persons (> 10) were available for these studies. No differentiation was made in the analysis of the test series, neither according to gender, nor according to age or height.

For the first test series, the measurement time was set to 20 minutes, there were two different movement states: on the one hand, a walking movement (stepping on the place) and on the other hand standing still (at rest), each in a fixed temporal rhythm. Extreme movements or fast movements were deliberately avoided in the course of this study, since such movements are or should hardly ever occur „in daily cleanroom routine". The corresponding average values were determined from the collected measured values and extrapolated with the calculated multiplication factor (ratio between air volume supplied via the FFU to the sample volume of the particle counters). The results (depending on the particle size) are listed in Table 1.

A very interesting side aspect of these studies was the individual measured values of certain test persons. Thus we were able to prove very well that private street clothes can be an

Test person		Average number of particles per minute per person			
		standing	walking	standing	walking
	♂ / ♀	≥ 0.5 µm	≥ 0.5 µm	≥ 5 µm	≥ 5 µm
1	♂	268	4,650	3	61
2	♀	65	1,460	2	49
3	♂	184	4,398	5	100
4	♀	113	2,179	8	52
5	♀	182	2,287	18	67
6	♀	346	5,547	7	112
7	♂	404	13,367	10	316
8	♀	189	3,895	1	35
9	♂	154	2,626	5	76
10	♀	58	798	6	33
11	♀	53	657	6	30
12	♀	13	1,998	0	92
13	♂	337	4,784	32	209
ø of all measurements		182	3,742	8	95
Actual particle number (extrapolated)		86,007	1,768,346	3,781	44,785

Table 1: Number of emitted particles per minute „People in street clothes"

Test person		Average number of particles per minute per person		Individual measurements	
		standing	walking	standing	walking
	♂ / ♀	≥ 0.5 µm	≥ 0.5 µm	≥ 5 µm	≥ 5 µm
1	♂	268	4,650	219 518 67	2,615 10,133 1,202
Actual particle number (extrapolated)		126,648	2,197,437	103,492 244,790 31,662	1,235,763 4,788,521 568,026

Table 2: Number of emitted particles ≥ 0.5 µm per minute of „a person in different street clothes"

extraordinary influencing factor with regard to the particle emission of a person (see Table 2). Depending on this private streetwear, the measured values for the same person varied by a factor of 8 (and more). This finding was decisive for the decision to define the so-called cleanroom undergarments firmly in all further series of measurements (with cleanroom lab coat, cleanroom overall etc.) in order to find the most uniform conditions possible under the cleanroom garments (in relation to the garments worn under it).

Particle release in cleanroom garments for classes ISO 7 to 9

Jogging suits made of 100% cotton (same cut, same date of production and all already cleaned several times) were chosen as the uniform undergarments. In this case, cotton garments were deliberately chosen, on the one hand because such clothing is often still worn under the cleanroom garments, and on the other hand to find a sufficient number of particles that can be measured. It soon became apparent that the test persons emitted significantly more particles with their jogging suit than with their personal streetwear. One explanation is that in the meantime a very high proportion of synthetic fibres is used and therefore less abrasion is produced.

The 2nd test phase therefore had to be slightly modified. In the 2nd phase, the test persons wore the defined jogging suit, defined cleanroom shoes, a disposable non-woven hood as headgear and a newly decontaminated (ASTM-A) cleanroom lab coat (made of a high-quality cleanroom fabric), as it is usually used in cleanroom classes ISO 7 to 9 (according to ISO 14644-1). Originally, the same „exercise programme" should be carried out as for normal streetwear. However, since all test persons wearing cleanroom garments consistently emitted more particles than in normal streetwear, the cause was quickly located – the cotton jogging suit. The procedure for phase 2 was then changed. The test persons first entered the Body-Box with the cotton jogging suits and cleanroom shoes and repeated the defined exercise program over 10 minutes. Then they left the Body-Box and put on the cleanroom lab coat and the disposable non-woven hood. After 2 minutes the test cabin was entered again and the test persons were allowed to „move freely" for 3 minutes (= acclimatisation phase with cleanroom garments). Afterwards, the same movement program (same sequence) as in the first test phase (standing/at rest and walking simulation) was started again.

The results of phase 2 are summarised in Table 3 (Note: 2 test persons were no longer available for the second phase).

Particle release in cleanroom garments for classes ISO 5 to 6

In the third phase the test persons wore the cotton jogging suit again as undergarment. On top of this, cleanroom overall, cleanroom full protective hood, knee-high cleanroom overboots, nitrile gloves and a 3-layer disposable face mask were worn. This garment arrangement is often used in cleanroom classes ISO 5 and 6 (according to ISO 14644-1).

The examination procedure, i.e. primarily the exercise program, remained unchanged (compared to the first two phases). As a precautionary measure, control measurements were also carried out during this study phase with cotton jogging suits only. However, the test persons had 8 minutes to change them. The results of this series of measurements are summarised in Table 4 (Note: 10 subjects were still available for the 3rd phase).

If the cotton jogging suit (under the cleanroom overall) is now replaced by undergarments suitable for cleanrooms (based on 100% synthetic fibres), the typical cleanroom clothing for use in aseptic areas is obtained. There have already been several studies with a similar design on the efficiency of defined cleanroom compatible undergarments. A study at the ITV Denkendorf is just one example, which showed that the number of detected particles and germs could be reduced by 50% or more by using cleanroom compatible undergarments – also in direct comparison to undergarments consisting of a cotton jogging suit [3].

Test person		Cotton jogging suit				Lab coat (above)			
		Average number of particles per person							
		standing	walking	standing	walking	standing	walking	standing	walking
	♂ / ♀	≥ 0.5 µm	≥ 0.5 µm	≥ 5 µm	≥ 5 µm	≥ 0.5 µm	≥ 0.5 µm	≥ 5 µm	≥ 5 µm
1	♂	764	36,986	17	711	203	4,883	4	83
2	♀	not recorded	not recorded	1	519	592	14,903	9	220
3	♂	not recorded	not recorded	26	450	473	7,291	6	108
4	♀	487	88,590	41	1,170	447	8,439	8	145
5	♀	1,230	46,257	30	535	166	4,938	4	78
6	♂	1,836	111,500	45	38	1,558	36,286	38	551
7	♂	2,972	27,836	60	554	318	4,673	78	3
8	♀	1,322	109,177	24	1,704	1,835	20,662	41	419
9	♀	8,388	126,366	146	1,780	1,019	12,172	20	196
10	♀	not recorded	not recorded	25	23	582	15,914	8	252
11	♂	1,016	74,983	28	1,511	529	16,600	12	300
ø of all measurements		2,252	77,712	40	818	702	13,342	21	214
Actual particle number (extrapolated)		1,064,162	36,724,068	19,032	386,430	331,742 approx. 31.2% of the initial level	6,304,946 approx. 17.2% of the initial level	9,795 approx. 51.2% of the initial level	101,172 approx. 26.2% of the initial level

Table 3: Number of particles emitted per minute „Persons in cotton jogging suit" and „Persons in cotton jogging suit and cleanroom lab coat above"

Test person		Cotton jogging suit				Overall + full protective hood + overboots (above)			
		Average number of particles per person							
		standing	walking	standing	walking	standing	walking	standing	walking
	♂ / ♀	≥ 0.5 µm	≥ 0.5 µm	≥ 5 µm	≥ 5 µm	≥ 0.5 µm	≥ 0.5 µm	≥ 5 µm	≥ 5 µm
1	♂	1,472	9,080	29	144	56	72	0.3	0.4
2	♀	144	165,050	1	2,114	120	376	1.2	3.1
3	♂	414	25,460	8	654	32	142	0.2	0.5
4	♀	75	115,690	8	1,405	58	256	1.0	2.8
5	♀	78	51,470	1	661	45	199	0.2	1.3
6	♂	2,810	82,940	41	1,182	67	352	0.7	0.4
7	♂	3,470	39,262	77	619	20	116	0.5	0.7
8	♀	755	145,310	14	1,729	37	118	0.6	1.6
9	♀	3,740	47,390	119	1,259	112	477	1.5	6.6
10	♀	893	68,920	24	1,043	59	140	0.4	0.7
ø of all measurements		1,385	75,057	32	1,081	61	225	0.7	1.8
Actual particle number (extrapolated)		654,505	35,469,460	15,122	510,845	28,827 approx. 4.4% of the initial level	106,328 approx. 0.3% of the initial level	331.0 approx. 2.2% of the initial level	851.0 approx. 0.2% of the initial level

Table 4: Number of particles emitted per minute „Persons in cotton jogging suit" and „Persons in cotton jogging suit and cleanroom overall + full protective hood and knee-high overboots above"

Clothing	Average number of particles per person					
	standing	walking	standing	walking	standing	walking
	≥ 0.5 µm	≥ 0.5 µm	≥ 1 µm	≥ 1 µm	≥ 5 µm	≥ 5 µm
Cotton jogging suit	873,304	34,955,780	657,312	25,114,780	17,077	448,638
Lab coat	331,742	6,304,946	130,901	2,506,495	9,795	101,172
Overall	28,827	106,328	10,396	32,135	331	851

Table 5: Number of particles emitted per minute „People in different garment systems" depending on movement

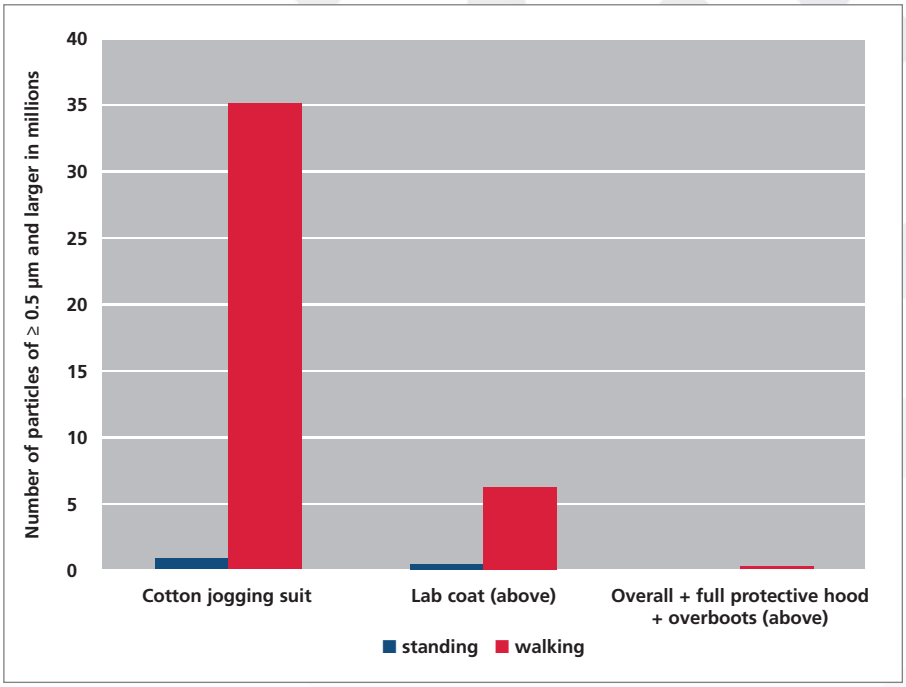

Chart 1: Number of emitted particles ≥ 0.5 µm per minute „People in different garment systems" depending on movement

Conclusion

The study has impressively demonstrated the range of human-induced contamination (in the case of undefined garments) that cleanroom operators have to reckon with.

Furthermore, these extensive studies also showed that this contamination risk can be minimized by means of a cleanroom garment system adapted to the required cleanliness process (Table 5 and Chart 1).

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