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TESTING THE EFFECTIVENESS OF CLEAN ROOM GARMENT SYSTEMS

ABSTRACT

Although the quantity of particles generated by human beings has not decreased, particle contamination from people is considered less of a problem in semiconductor wafer fabs than in years past. This improvement is primarily due to advancements in the technology of clean room garments and to the widespread use of advanced garment systems in the semiconductor industry.

In order to choose the most effective garment system, sophisticated test procedures must be used to distinguish between high inherent variability and real differences in performance among competing garment strategies.

This paper describes key considerations for effective testing of aerosol particle generation from personnel. Experimental design is reviewed in detail including sources of variability in the data and ways of effectively dealing with that variability; the relative merits of various air sampling mechanisms; and the isolation of particles generated from specific personnel locations including the head, foot area, body, and hands.

INTRODUCTION

Several methods are used to test the effectiveness of clean room garments (1) including tests on the ability of the fabric to efficiently filter particles, the propensity of the fabric or garment to generate particles or lint, and the tendency of the fabric to allow moisture or air to pass through it.

All of these methods are limited because they fail to take into account the ability of the suit to conform to the person wearing it and to prevent particles generated by that person from reaching the clean room atmosphere. In other words, a poorly-designed garment of even the best fabric will not perform effectively. Such a situation will not be identified by lab testing, but must be tested with the human being inside the suit.

Of course, there are significant problems with setting up such a test. First, particle count data tends to be highly variable and does not tend to follow a normal distribution (on which most traditional statistical tests are based). In addition, garments fit differently on different individuals, and individual people tend to particulate at vastly different rates from one another and at different rates from day to day. These factors must be accounted for in the experimental design in order to provide a fair trial for each of the systems under consideration. (2)

The following considerations apply to response factors of either airborne particle counts or particles added to the surface of "witness wafers" laid out in the test vicinity to collect particles from the air.

TEST ENVIRONMENT

Isolate the test area. Perform aerosol particle testing in an isolated area, away from people or equipment which may contribute unplanned particle bursts.

The best way to satisfy this requirement is to test in a totally separate "mini clean room" which is used only for testing purposes. The next best situation (a close second) is to test in an unused bay of a raised-floor, vertical laminar flow Class 1 cleanroom.

Other test conditions may not work at all. For example, testing in turbulent air flow or near operating equipment makes it likely that contamination generated by other sources will interfere with the signal you are trying to measure and prevent its identification.

Reduce the level of background noise. Testing should be performed in the cleanest area available with background airborne particle counts of zero if possible. Measure background counts for an extended period prior to testing (ideally for 24 hours) to verify the consistent cleanliness of the test area.

It may be necessary to monitor a particle size larger than the minimum detectable, in order to achieve background particle counts of zero. Even low levels of background counts are undesirable due to significant fluctuations caused by the randomness of particle distribution in air and to inconsistency of particle sources.

GARMENT SYSTEMS

Tests of particle control while garments are in use are inherently time-consuming to conduct, and subtle differences between garment strategies may not be detectable at all because of high variability. If too many questions are addressed, the testing will multiply in complexity to the point where the cost of obtaining the answers will far exceed the value of obtaining them.

One effective strategy is to compare the existing garment system with one or two competing systems proposed as alternatives. The existing system should be included in the experiment to verify that the proposed investment in a new system can be expected to provide real benefits.

When selecting the system to test, try to eliminate "noise" from other areas of the body not in current consideration. For example, even if your final system will not include clean room overboots, you may wish to have subjects wear them during the testing to eliminate particles from the feet as a source of random noise. (Especially if the airstream that you will be sampling is downwind of the test subjects' feet.) The same reasoning argues for effective covering of eyes, face, head, and hands.

MOTION PROTOCOLS

Obviously, any clean room garment system must function effectively while the subject is in motion. To test the in-motion effectiveness of the system, the subject is asked to perform various exercise protocols. These protocols should simultaneously represent the full range of motions the garments are likely to see in use and be gentle enough for each subject to perform for several minutes. Some motion protocols typically performed are listed in Table 1.

A timing device (such as a musician's metronome or a strobe light) should be used to keep the subjects' rates of movement relatively constant. A typical pace is one beat per second. Frequently, a one-minute resting period is allowed between different motion protocols to allow the measurement system to clear out.

RESPONSE VARIABLE

Sample carefully and rationally. To measure the particle contribution from people, sampling mechanisms must be located "downwind" from the person being tested. For each new test location or change in conditions, the local air flow should be characterized using a liquid nitrogen fog or other non-contaminating method. In even the best designed clean room, local obstructions, air pressure balancing, and other factors will affect air flow so that it is not 100 percent vertical.

Table 1 Typical motion protocols

Body Area Tested	Protocol Name	Protocol Description (Vigor)
Body	Reaching	Alternate reaching left and right arm in and out in front of body. (Gentle)
Body	Double Reach	Reach both arms out in front, then pull in to sides of body. (Gentle, some puffing)
Body	March & Slap	While marching in place, pat shoulders, thighs, and backside in turn. (Vigorous)
Body	Stand & Pat	Pat shoulders, thighs, and backside in turn. (Somewhat vigorous, 3 seconds for full cycle)
Body	Deep Knee Bends	Perform three deep knee bends at your own pace, then wait out rest of minute. (Vigorous)
Foot	March in Place	March in place with arms at sides.
Head	Count Out Loud	Count in normal tone of voice.
Head	Pat Head	Pat top of head.
Head	Turn Head	Turn head from side to side.
Hand	Abrade & Open	Rub thumb across pads of fingers to thumb and open quickly (two seconds for full cycle).

For airborne particle counting, our goal is to sample a representative sample of the particles generated. Three common strategies to achieve this are:

a) To capture all the exhaust air, mix it using a system of baffles, and measure a sample of the mixed air (generally used in "body box" configurations.)

b) To sample from a larger area of the downstream air to capture a larger proportion of the generated particles (see the GORPLER® aerosol sampler in Figure 1).

c) To enclose the area being measured to avoid dilution from the ultraclean vertical laminar flow air and sample within the enclosure as was done for the glove "chamber test" described below.

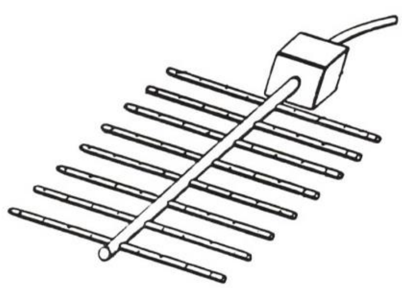


Figure 1 GORPLER® aerosol sampler

The following sampling configurations have been found effective for typical testing situations.

Entire garment system. One means of testing the entire garment system is to use a specially constructed body box to capture all of the air which may have been in contact with the subject, mix the air, and sample a portion of that air. Generally this configuration consists of a small-footprint body box fitted with 100 percent ULPA filters on the ceiling with a full vertical laminar flow of at least 70 feet per minute. Air is captured, mixed, and sampled after it flows through the grated floor of the body box.

In this case, the entire body must be covered with the garment system under consideration as spurious counts from even a small uncovered portion of the body may outweigh the differences among the garment systems that you are trying to test.

Another method of sampling particles accumulated from the entire body is to mount an area-based sampling probe (such as the GORPLER sampling probe) under a grated pedestal raised off of the floor a few inches. In order for these counts to be representative, the area used for testing must have a true vertical laminar flow with a raised floor or else air flow currents along the floor will interfere with representative sampling.

In some cases, the value of most interest is the quantity of particles affecting product at table height or workstation level. A sampling probe mounted at waist height in front of the subject will pick up these particles. The only caveat to this configuration is to make sure that the "front of the subject" is situated downwind of any horizontal component of the airflow.

Entire garment system except the boots. In one recent study the entire garment system except the boots was sampled by mounting a sampling probe at ankle height in front of the subject. Although this room was a Class 1 vertical laminar flow clean room, there was a slight horizontal component to the air flow due to positive pressure between the process bays and the corridor. The subject was situated so that the air tended to flow over the subject, then into the sample probe. Non-marching motion protocols were used to avoid kicking the probe.

Head and face area. A sampling probe at waist level in front of the person will pick up some particles generated in the head area, especially if the subject bends forward slightly. Additionally, a second probe in front of and slightly below the subject's face may be more successful at detecting locally-generated particles. The face-height probe should be adjusted for the heights of all subjects tested. (See Figure 2)

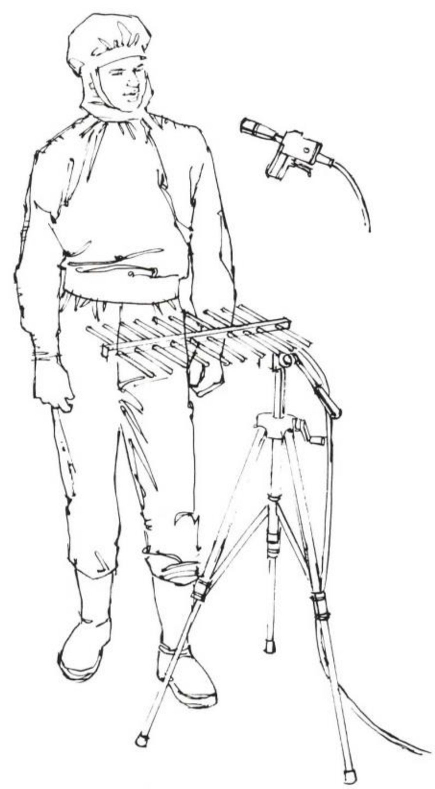


Figure 2 Aerosol sampling probe arrangement for testing hand and face area

Hand area. The hand has such small physical dimensions that particles generated from the hand area can be easily diluted and swept away from your sampling probe before detection. In order to increase the likelihood of detection, a small chamber to enclose the hand has been found to effectively concentrate emitted particles for easy detection.(3)

Such a chamber is easily constructed of any clean material and can be used to detect significant differences among glove types, to estimate the variability from glove to glove in the same type, and to track performance over time. Care must be taken to wear effective clean room garments over the remainder of the body to avoid contamination of the air being drawn into the chamber.

Foot area. To measure particles generated at the foot area, sample air that has flowed past the feet while minimizing the particle contribution from the rest of the body. A body-box configuration, where the air is sampled from the bottom of the box, will enable you to measure downstream from the feet, as will a probe mounted below a raised grated floor on which the subject stands.

In order to minimize particle contribution from the remainder of the body, an effective garment system must be worn and the subject must hold their body still.

SAMPLE SIZE

Use large sample sizes. Particle count data tends to be highly variable, so lengthy sample times may be necessary to detect a statistically significant difference between garment systems. The average number of particles per minute of a four-minute sample will have half the standard deviation of a one-minute measurement.

In order to test a fair representation of the population and a sufficiently large sample size, at least six to eight people should be tested. The quantity of airborne particles may vary from person to person one hundredfold, so a statistically significant result requires the testing of several subjects. In addition, differences in garment fit, or in the ways that people move, will cause variability in results from person to person.

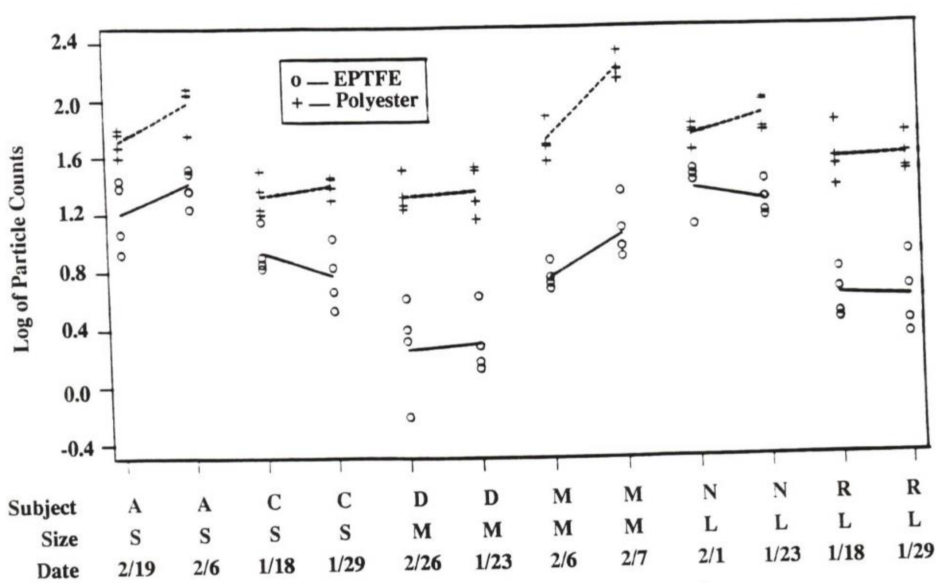
The chart in Figure 3 shows (among other things) the variability in results from person to person and from day to day, even for the same person. Each pair of points on the "X" axis represents one person and each point in the pair represents the results from one day's testing. The "Y" axis is scaled by the logarithm of 10, so the difference between the EPTFE results on 2/26 for subject D, and the EPTFE results on 2/1 for subject N differ by more than ten times.

EXPERIMENTAL CONTROLS

In order that each system under consideration should face the same test challenge, each subject should be tested in all garment systems in the same test period on the same day. Otherwise, the subjects' challenge to the system may change significantly (as when different clothing is worn under the clean room garment system) and provide an unfair advantage to one of the systems under evaluation.

Other important controls on this type of experiment include a thorough cleaning of all garments under consideration (preferably at the same time, at the same laundry), the use of a timing device, such as a metronome or strobe light to keep subjects' motions relatively constant, and the use of the same particle counter or surface scanner throughout the experiment.

Particle Counts at Workstation Level During March and Slap



Particles per cubic foot which are greater than 0.3 μm

Figure 3 Variability among subjects and from day to day for the same subject, can be substantial.

If you are measuring particles accumulated on witness wafers, one means of controlling for particles added during the measurement process, or drift in the calibration of the surface scanner, is to keep several wafers in a closed box during the experiment. Any particles added to these wafers must be due to either the measurement process itself or to fluctuations in the sensitivity of the surface scanner. Flats of wafers should always be aligned during the measurement process to reduce measurement variability.

The order of garment systems tested should be randomized. Due to fatigue, the subjects' motions will vary somewhat throughout the study. Randomizing the order of testing will allow the effect of subject fatigue to be spread evenly over the garment systems.

DATA ANALYSIS

Because particle counts are so highly variable, it is particularly important to use care in data analysis techniques. A consultation with a qualified statistician will save many headaches by insuring that the information collected will be adequate to answer your questions without overtesting and wasting valuable resources. After the data is collected, the statistician should be consulted again to assist in the choice of analysis methods.

Data resulting from real-world experiments should be analyzed two ways. The first and often the most telling way is to plot the data on a graph, comparing the correlation of all the independent variables with the observed response variables. Often the story will be quickly revealed by observing such graphs. Patterns will immediately "jump out" to the human eye that may have taken days of careful numerical analysis to uncover.

One practice to avoid is that of discarding data points simply because they are "out of line" with the other data collected. Extreme data points often contain the most valuable information of the entire experiment.

When analyzing particle count data we should not assume that traditional statistical tests may be used on the raw data. Data need to be tested for normality before applying statistics which assume the normal distribution. Airborne particle count data frequently approximate the log normal distribution, and this can be accommodated by taking the logarithm of the raw counts before analysis.(4)

A possible solution is to use non-parametric data analysis techniques. These techniques produce conclusions which tend to be valid no matter what the underlying distribution of the data is.

Finally, after the data are thoroughly understood, results may be presented in a simplified form, such as a bar graph, in order to communicate rapidly with a third party decision-maker. The bar chart by itself, however, does not communicate enough information to the analyst, as only the average effects can be seen. Missing are such important considerations as the spread (variability) of the response distribution and the pattern of the results.

CONCLUSIONS

In order to obtain meaningful results, experiments to test the effectiveness of clean room garments in "in-use" conditions must be carefully designed. This paper addresses many of the problems that must be taken into consideration and a few of the means by which these problems have been successfully addressed.

ACKNOWLEDGEMENTS

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