

Quality Management in the Automotive Industry

Part 2

Technical cleanliness in assembly

Environment, Logistics, Personnel and Assembly Equipment

1st edition 2010

Technical cleanliness in assembly

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Foreword – Using the guideline

As clients of the Fraunhofer IPA, members of the MontSa industrial alliance are given the jointly written version of a work paper concerned with cleanliness in assembly in the form of a consolidated final report.

The final report forms the basis of a guideline which is planned to be released by the VDA Quality Management Center (VDA-QMC) as VDA Volume 19.2 with the title “Technical cleanliness in assembly – Environment, Logistics, Personnel and Assembly equipment”.

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A: SCOPE OF APPLICATION AND VALIDITY

A.1 Background

The guideline is intended as an aid for planners and quality management staff involved in the planning of new processes and sequences or the optimization of existing ones in assembly areas and their environments where cleanliness is a critical factor.

In many fluid circuits found in automobiles (e.g. fuel systems, brake circuits, lubricating and hydraulics systems, cooling and air-conditioning systems, air intakes or exhaust systems and further treatment) as well as in mechanical and electronic units, contamination through particles may cause functional impairments. In such cases, the separate system components are generally cleaned after manufacture and the level of cleanliness needed for them to function is specified and tested (VDA 19 Inspection of technical cleanliness – particulate contamination on functionally-relevant automotive parts). In subsequent manufacturing steps, there is a danger that the initially clean components become recontaminated through transportation, storage, provision and especially assembly as a result of the generation or entry of particles. If such sensitive system components cannot be cleaned after assembly, there is a risk that particulate contamination will remain in the end-product and impair its function and that the cleanliness specification of initially-clean separate parts cannot be upheld.

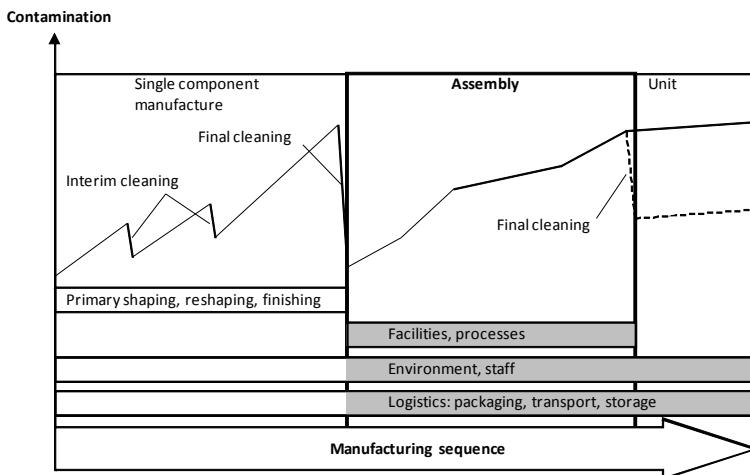


Fig. A.1: Contamination of components and aggregates / assemblies during manufacturing processes. Focus of the guideline in the field of assembly.

The aim of the guideline is to prevent the generation of critical particulate contamination at sensitive sites, to remove unavoidable particles and to protect components and assembled systems against the entry of particles from the surroundings. As not every particle source in a considered environment is automatically critical to the function of a completed product, the guideline also aims to name the relevant sources. This is required in order to take the correct technical and cost-effective measures and to avoid unnecessary costs having no appreciable benefit for the end-product. As well as aiming to fulfill the technical aims, the guideline also serves to standardize procedures for planning and optimizing cleanliness-sensitive assembly areas.

Requirements for the measures to succeed and thus the starting point of the guideline are:

- A cleanliness specification for components and aggregates, i.e. finding out which particles may be critical to functions.
- Single parts or aggregates which fulfill the cleanliness specification (e.g. after final cleaning in mechanical production).

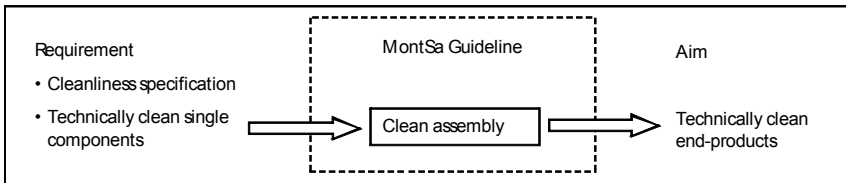


Fig. A.2: Requirements and aims of the guideline for cleanliness in assembly.

Current state of knowledge and technology

In many industries where cleanliness is crucial to product quality, standards, guideline or norms for cleanliness-suitable manufacturing have been established, e.g. in the semiconductor and pharmaceuticals industries or in medical technology. In the field of technical cleanliness, i.e. the avoidance of functionally critical particles in the automotive and supplier industry, up till this year standards for testing the technical cleanliness of components have existed but no guidelines regarding their manufacture or subsequent processing.

The measures and aids required to ensure appropriate cleanliness levels in assembly processes and their environment are mainly concerned with the avoidance of the particles considered to be critical. For this reason,

measures used for this purpose in other industries cannot generally be applied in the automotive and supplier industry or only be implemented after careful testing. Also, the adoption of solutions from other industries and / or applying them to solve other problems is often associated with extensive costs and may not improve technical cleanliness levels. For example, many measures implemented in the fields of medical technology and pharmaceuticals aim at reducing the number of living micro organisms, while other measures used in the microelectronics industry in ISO 14644 cleanrooms aim at controlling airborne particles < 5 µm. Both bear very little relevance to the manufacture of technically-clean systems in the automotive and supplier industry.

The guideline has been developed to specifically support the process of implementing cleanliness-relevant measures in the automotive and supplier industry. It also helps to identify and eliminate relevant particle sources and avoid the making of false investments in inefficient cleanliness solutions.

Faults due to particle contamination

Depending on the size and number of particles present and on the constructional features of the system being manufactured, contamination may impair a component's operation or even production in various ways:

1. **In operation:** single particles of a critical size may cause functional impairments of a technical system, e.g. if they are present on the seal seat of a valve in a bearing gap or in constrictions (nozzles, conduits). The effects may range from leaks to a complete breakdown of the system due to jamming or short circuiting. Especially in the case of fluid circuits (fuel, lubrication and hydraulic systems, cooling circuits and air and gas-conducting areas), it is not only essential to ensure the cleanliness of components liable to break down but also of the whole system due to the potential mobility of the particles.

Components and systems contaminated by particles may also be subject to increased wear.

2. **During production:** even before it is put into operation, faults may occur in a component or system due to particulate contamination:
 - Feed force, breakaway torque or exact positions may become altered due to the presence of contamination on the contact surfaces of joining partners, resulting in faulty connections (e.g. screw connections wrongly pre-tensioned resulting in "seating" during operation, or a jack inserted crookedly).

- Contaminated contact surfaces of sensors and workpieces may cause pseudo defective goods. The same principle applies to optical inspection.
- As a rule, the cleanliness of workplaces and facilities plays an important role in improving quality and reducing the number of process errors. This point is often taken into account within the scope of 5S measures. However, from the point of view of technical cleanliness where direct risks associated with the entry of critical particles into components are considered, these aspects are less important. Despite the presence of visible contamination in an assembly environment, cleanliness-suitable manufacturing is still feasible provided careful considerations are made and appropriate measures taken. Nevertheless, general cleanliness in the manufacturing environment also supports the technical aspect of cleanliness, especially through the conduct and way of thinking of the people concerned.

A.2 Scope of application

A.2.1 Particles

The measures described in the guideline are concerned with particles greater than 5 µm in size in compliance with VDA 19 or ISO 16232 Part 10 respectively.

Comment: Not all particle sizes specified in VDA 19 or ISO 16232 Part 10 necessarily need to be taken into consideration in the design and optimization of a cleanliness-suitable assembly facility. The particle size which is relevant depends upon the cleanliness specification of the component, aggregate or system. For the vast majority of systems in the automotive industry, the particle size of 25 or 50 µm and larger is generally sufficient.

A.2.2 Application and implementation

After verification and alignment with the requirements for an assembled aggregate or product, the aspects dealt with in the guideline can be used as a basis to develop:

- Procedures
- Checklists
- Work instructions
- Training courses
- Performance specifications

They can be used when **planning new** or **optimizing existing** cleanliness-sensitive assembly facilities as well as in CIP or accompanying cleanliness controls.

The contents of the guideline and measures stated within are concerned with particle sources in assembly facilities and their environments (see Figure A.1). **Chapter E: Personnel, C: Environment** and parts of **Chapter D: Logistics**, but can also be transferred to other cleanliness-sensitive areas of manufacturing (e.g. single item production or product handling). The sense behind implementing measures also needs to be individually verified, especially if parts are subjected to a final cleaning process or if the end-product is closed on all sides.

The guideline is based on cleanliness problems encountered in the automotive and supplier industry. Where similar problems exist in other industries with a comparable critical particle size range, the essence of the contents of the guideline can be transferred

A.3 Exclusions

The required degree of cleanliness of bought parts and in-house manufactured components to be assembled must be safeguarded and can be monitored, for example, by carrying out specific cleanliness checks (VDA 19). How the required degrees of cleanliness of supply parts are achieved does not form part of this guideline. The following topics are therefore not dealt with:

- Component cleaning techniques (except those which can be integrated into assembly)

- Component design with regard to easy cleaning
- Suitable machining of parts from the point of view of cleanliness (e.g. producing small chips or minimizing burrs)
- The need to design or optimize an assembly facility with regard to cleanliness depends upon the technical necessities of the system requiring assembly. The existence of this guideline alone cannot be used as a basis to:
 - Compile limiting cleanliness values for components, aggregates and systems
 - Generally design all assembly facilities and environments with regard to cleanliness
 - Carry out cleanliness audits

The guideline helps to locate and eliminate particle sources in cases where the required degree of cleanliness of the assembly system cannot be attained despite the use of adequately clean single components.

B: DESIGNING A CLEAN ASSEMBLY FACILITY

B.1 Introduction

The quality of cleanliness which can be attained for a fully-assembled product is determined by the interaction of numerous factors in the process chain.

The aim of the guideline is to structure the broad spectrum of influencing factors and associated causes as well as to provide solutions in compact form for planning engineers and quality management officers. Additionally, in order to carry out cleanliness-suitable planning and optimization in a targeted and effective manner, features regarding contamination mechanisms and critical particle sizes which are specific to the automotive and supplier industry have also been taken into consideration when determining recommendations, procedures and test techniques. To implement this approach comprehensively and separate this industry from other contamination-sensitive industries both from a technical and language point of view, the manufacturing environment of a cleanliness room or cleanliness zone, for example, is developed and defined. This enables a controlled area for carrying out clean tasks to be designed which is not primarily defined by air quality and therefore deliberately set apart from conventional cleanroom industries. As well as having technical aspects, Cleanliness rooms and cleanliness zones also sensitize workers about cleanliness-suitable conduct – technical cleanliness through care.

In the chapter, the various factors influencing cleanliness are grouped into different topics and thus into separate chapters of the guideline. The chapter is also concerned with the basic tasks associated with cleanliness-suitable design, the concept and application of the guideline and explanatory notes regarding implementation of the guideline in practice.

B.2 Fundamentals

B.2.1 Particle generation and mechanisms of transport

In many cleanliness-sensitive industries, during their manufacture components need to be protected against the entry of critical contamination via the environment. In hygiene-sensitive industries, this could be contamination with micro organisms from the environmental atmosphere, personnel or via contact with surfaces. In the microelectronics industry, particles in the sub-micrometer range have to be filtered out of the ambient air or process media (liquids and gases) to ensure that products do not

become contaminated on coming into contact with them. In the automotive and supplier industry, one aspect regarding assembly facilities and environments is especially critical: the generation of particles directly at the level of components and aggregates due to clamping, joining or other assembly processes. In logistics, critical contamination can also be generated as a result of abrasion between packaging materials and components. These types of particulate contamination are especially relevant for two reasons.

- Particles can be generated during assembly and assembly processes; due to their size, shape and material, they may impair functions much more severely than particles sedimenting from the environment.
- Particles generated during assembly and assembly processes originate directly at component level and thus carry much high risks as far as the cleanliness-sensitive functional surfaces of assembly units and products are concerned.

Note: Particles generated from joining metallic components may be much more critical with regard to functional damage than fibers sedimenting from the environmental atmosphere. This was proved in the course of numerous accompanying tests carried out during compilation of the guideline.

However, in order to ascertain which particle sources are critical, each manufacturing environment needs to be assessed and the sensitivity of components with regard to certain forms of particulate contamination evaluated individually. When planning a new or optimizing an existing cleanliness-suitable assembly facility, all potentially critical particle sources need to be taken into account.

One characteristic which distinguishes the automotive and supplier industry from the conventional cleanroom industry as far as cleanliness is concerned is the particle size affecting the function of completed aggregates. For the majority of systems, currently (2010) single compact particles ranging between 200 and 1000 μm in size (or larger) are generally responsible for malfunctions and cleanliness specifications are therefore implemented accordingly.

Once they have been generated or emitted into the environmental atmosphere, particles of this size tend to follow their impulse and gravity (ballistic particles) which means they do not travel very far. Only very small or lightweight particles become airborne and remain mobile in the air for longer periods of time, e.g. through Brownian molecular motion. Cleanroom technology measures, such as filtering the circulating air (see **Chapter C: Environment** Particle dispersibility diagram), only apply for “dispersible” particles.

Particle transport mechanism	Relevance regarding component recontamination
Transportation via the environmental atmosphere	Low
Ballistic spread	High but localized
Gravity	Very high but localized
Displacement via surfaces or personnel	High

Table B.1: Particle transport mechanisms and their relevance regarding component contamination.

B.2.2 Grouping particle sources

The system considered in the guideline begins once single parts have been subjected to a final cleaning process to attain the cleanliness level required by the specification (see Figure A.1 **Chapter A: Scope of application and validity**). Here the risk of recontamination due to numerous processes and influencing factors starts, such as those listed in Figure B.1. The influence of external particle sources from assembly facilities and the environment only ends after final assembly when a product is a closed system.

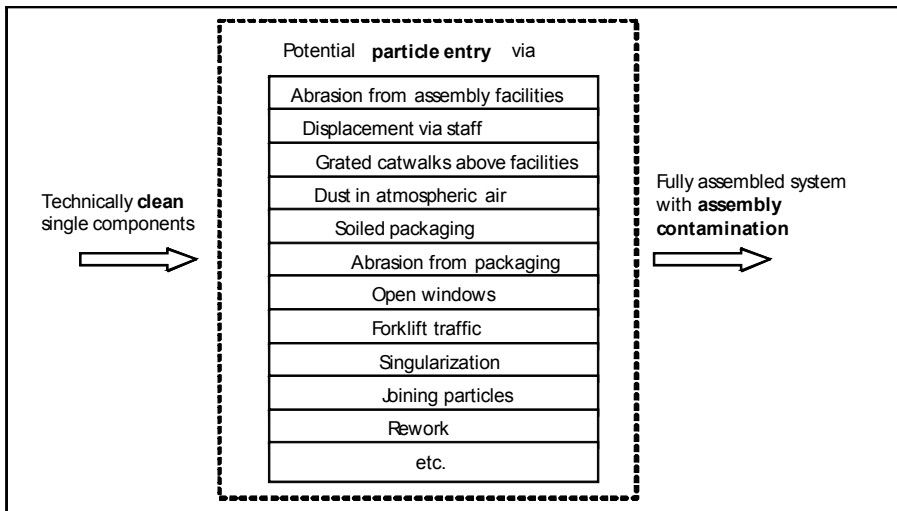


Fig. B.1: Examples of cleanliness-relevant factors influencing the phase between single item production and the completed system.

Numerous tests and company surveys show that these influencing factors were not assessed in a standardized manner in the past. This resulted in very different approaches being implemented to reduce recontamination in the various industries or industrial locations, and was associated with different degrees of success and highly fluctuating costs.

In order to structure and standardize the procedure, in the guideline influencing factors have been grouped into the following areas:

- Environment
- Logistics
- Personnel
- Assembly facilities

in line with the chapters of the guideline.

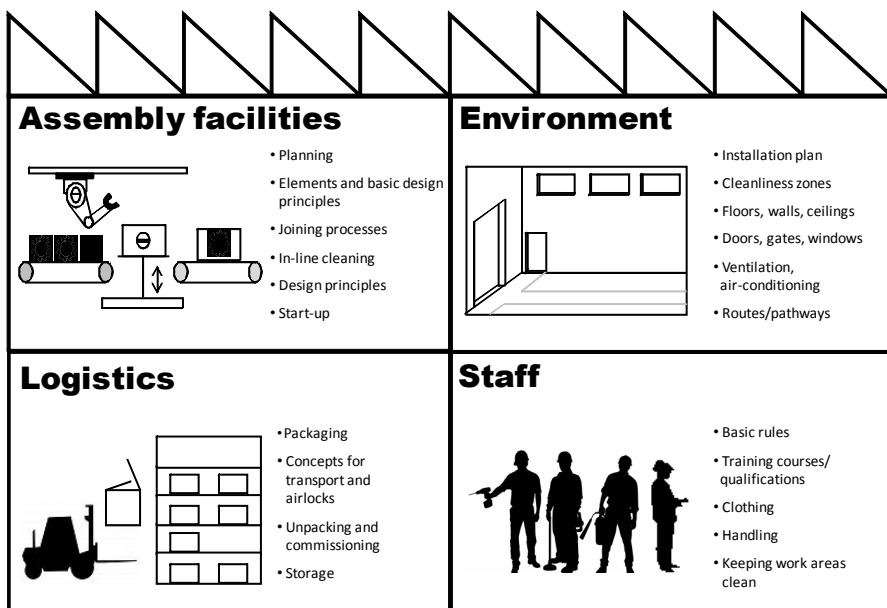


Fig. B.2: Grouping factors influencing cleanliness into subject areas in line with the chapters of the guideline

Note: The depiction of the area of application of the guideline in Figure B.2 as a “factory building” highlights the system border between “assembly facility and environment”. However, this does not necessarily mean strict controls for a factory building or company; instead, because logistics processes have also been included, the figure may also apply beyond the limits of companies or locations.

In each chapter, every influencing factor is considered in sufficient detail so as to allow particle sources to be efficiently assessed and optimized / reduced. In the case of some influencing factors or particle sources, several aspects may need to be taken into consideration. The inner surfaces of packaging, for example, may not only cause direct contamination of the component through abrasion but also the outer surfaces have an indirect effect on the cleanliness of the environment. Members of staff are an indirect particle source due to the clothing worn (which give off fluff) but are also a direct particle source as a result of their conduct and execution of their (assembly) tasks.

B.2.3 Basic principles for controlling and minimizing damaging particles

In general, a particle source becomes more critical:

- The closer it is to the component
- The longer the component is exposed to it
- The higher the number of functionally critical particles is generated by it

Depending on the type and size of the particles considered to be functionally critical and the transportation methods implemented, the following basic principles for controlling them apply:

- The generation of functionally-critical particles directly at the level of the component or assembled system must be avoided.
- No surfaces or media coming into direct contact with the component, e.g. tools, auxiliary products, packaging materials or gloves, may contain any functionally-critical particles.
- Sources of functionally-critical particles above the component or aggregate must be avoided or screened.
- The stirring up or emission of functionally-critical particles into the immediate environment of the unprotected component or aggregate, e.g. through forklift traffic, uncontrolled use of pistols operated with compressed air or strong gusts of wind, must be avoided or screened.
- If particle entry cannot be reduced to a non-critical level, it must be verified whether particles can be specifically conducted away or completed aggregates subjected to a final cleaning process in order to remedy the situation.

These considerations are to be made if particles could attain the cleanliness-sensitive functional surfaces of a component or aggregate. This is limited if components are encapsulated and functional surfaces are on the inside, for example.

In many cases, cleanliness improvement measures are associated with investment or operational costs. To keep costs as low as possible, clean assembly facilities are designed and optimized in the guideline according to the following principles:

1. **As clean as necessary, not as clean as possible:** only particles which could affect the function of the components and aggregates are kept at bay. Thus, the cleanliness specification is the basis for planning and optimization.
2. **From the inside to the outside:** particle sources become more and more critical the closer they are to components or aggregates. Therefore, in the guideline a differentiation is made between direct and indirect influencing factors and derived measures are prioritized. As a result, particle sources in direct contact with the component are eliminated first before measures in the surrounding area are taken.

From a technical and economical point of view, it is rarely possible in a complete assembly facility to avoid all particles considered to be functionally critical in the environment and in all logistics processes. However, such particles may not reach the cleanliness-sensitive functional surfaces of components or aggregates. This can be achieved by screening particle sources from components or by taking steps to ensure that unprotected, cleanliness-sensitive areas of components are only exposed to unavoidable particle sources for as short a time as possible.

Note: By maintaining distances between particle sources and cleanliness-critical areas, a cleanliness-optimized facility may require more space than a conventional one. Faster sequences, such as installing a component as soon as it is removed from its packaging, reduce the risk of recontamination and may render further protective measures such as encapsulation obsolete.

B.3 DESIGN

B.3.1 Concept

Initial situation

The starting point for all further considerations is the cleanliness specification of the component, aggregate or assembly system. The aim is to effectively prevent the entry of particles during assembly and neighboring processes which, according to the cleanliness specification, may not be found in the component. The more information is known about the functionally-critical particles, the more efficiently cleanliness-relevant measures can be derived.

The minimum amount of information required is the particle size which may not be present. This can be obtained from a cleanliness specification in accordance with VDA 19:

- In the case of a specification with particle counts per size class, this equates to the first size class where no particles may be found
- In the case of a specification of the maximum permissible particle size, no particles larger than this may be present

Note: If the cleanliness specification is only specified as a gravimetric value, the permissible particle size cannot be derived, i.e. the specification is not suitable for deriving further measures for the factory without obtaining further information.

Comment: In fluid circuits, it may be the case that not only single, large functionally-critical particles may be relevant but also the number of smaller particles which, for example, could be largely responsible for wear of a system. As a rule, high particle counts due to abrasion which affect wear are only discovered during operation of a system and these determine the point in time when operating fluids require changing. If this aspect needs to be taken into consideration during the manufacturing process, particle sources in the assembly facility and environment need to be assessed with regard to the quantity of micro particles generated as well as with regard to large characteristic particles which are absolutely forbidden.

Knowledge of other features, such as the material or shape of functionally-critical particles and especially information about particles which are not damaging even if they exceed the permitted size, is very helpful and may contribute significantly towards reducing the effort and costs involved in designing a cleanliness-suitable assembly facility.

- Note 1:** Explanatory examples:
If, for example, only metallic conductive particles above a certain size are critical because an assembled system contains electronics with conductive paths which could be short-circuited by such particles, only those processes where such particles occur require optimization.
If textile fibers, which are unavoidable where personnel is present, are not critical to a product, there is no requirement to take expensive measures to filter the air or regulate personnel clothing.
- Note 2:** As well as observing the cleanliness specification of single components, when assembling cleanliness-sensitive aggregates special attention should be given to the dimensional tolerances of joining partners. They are to be selected in such a way so as to ensure that no particulate abrasion takes place during the assembly process as this would not only violate the cleanliness specification but also be impossible to remove from the aggregate. This also applies to the design of workpiece receivers and clamping devices if there is a risk that functionally-critical particulate abrasion could occur from them.

Indirect influences

These factors are concerned with particle sources which are not in direct contact with the component. In such cases, the negative effect on the cleanliness of components and aggregates is generally much smaller than with direct influencing factors. This is shown by the narrow arrow on the right-hand side of Figure B.3. The cleanliness task here is to protect components against particle entry. As the particle transport mechanisms are known and generally apply (see Table B.1), decisions about design and relevant measures can be made.

The exact design and appropriate measures depend upon the cleanliness grade (CG). The choice of cleanliness step is described in **Chapter C: Environment** and is made on the basis of the cleanliness specification and thus particles critical to functions. Based on a particle dispersibility diagram, preliminary estimations can be made whether manufacturing processes should be carried out in a controlled area (cleanliness zone or cleanliness room) or in a cleanroom.

The cleanliness grade chosen involves further decisions which affect:

- The room concept (see **Chapter C: Environment**)
- The aspect of logistics called “external logistics” which describes the influence of packing and unpacking procedures on the manufacturing environment. The appropriate measures and regulations, such as lock concepts, are dealt with in **Chapter D: Logistics**.

- Staff clothing; these are discussed in **Chapter E: Personnel**.

Note: The determination of a cleanliness grade does not necessarily apply to a whole room or hall. It may be highly localized if the risk of contamination only exists in a specific area, e.g. where cleanliness-critical functional surfaces are open to the air. A cleanliness grade can also be created temporarily, e.g. when components with cleanliness requirements are manufactured.

Direct influences

This comprises particle sources which are generated as a result of a direct interaction with components, or during handling or assembly. Compared with indirect influencing factors, the risk of particles being introduced into components and aggregates due to the influencing factors is very high. This is shown by the broad arrow on the left-hand side of Figure B.3. The task to be solved in order to remain within the limits of permissible component cleanliness values is to **avoid** functionally-critical particles, i.e. deactivate such particle sources. As these sources may vary considerably depending upon the component, aggregate, assembly process, joining parameter, packaging, etc., it is not possible to determine measures or solutions which are generally applicable. However, **assistance** can be given to suppress or confine particle sources. If critical particles cannot be avoided, a supplementary or alternative task is to **remove** them by way of either a final cleaning process or one integrated into the assembly.

The planner involved in the process of finding a solution to this specific problem can find useful information in:

- **Chapter F: Assembly equipment**, with regard to the design of processes and systems as well as operation and maintenance.
- **Chapter D: Logistics**, with regard to the design of internal logistics, i.e. direct component packaging.
- **Chapter E: Personnel**, with regard to the conduct of personnel in direct contact with the component.

Verification

A requirement for the cleanliness-suitable design and operation of a facility is an appropriate test technique for **locating and evaluating particle sources** and for **qualifying cleanliness-relevant measures**. Suitable test techniques and their implementation are described in **Chapter G: Assessing cleanliness factors**.

As soon as the influence of contamination due to processes carried out on a component can be tested and especially particles from assembly processes analyzed directly at the level of the component or inside it, tried and trusted extraction procedures such as those described in VDA 19 can be implemented.

One of the test techniques described in this way for the first time is the use of so-called particle traps to collect particles sedimenting from the environment. It is based on the placement of self-adhesive test surfaces of a defined size for a defined period of time. Depending on the task in question, it is possible to ascertain the quantity of particles generated by each process or the general cleanliness level of the environment, which can then be represented by an overall value. To analyze the particle traps, automated microscopes can be utilized in the same way as for counting analysis filters according to VDA 19.

The results and information obtained from the test procedures described in **Chapter G: Assessing cleanliness factors** can be used to:

- Locate critical particle sources.
- Verify specific cleanliness-relevant optimizations, e.g. to assembly processes.
- Assess a manufacturing environment to see if it is suitable for clean assembly.
- Ascertain whether certain factors have an effect on the cleanliness level of components or aggregates.
- Gain experience from running processes and to use it to plan new facilities.
- Visualize and document particle sources.

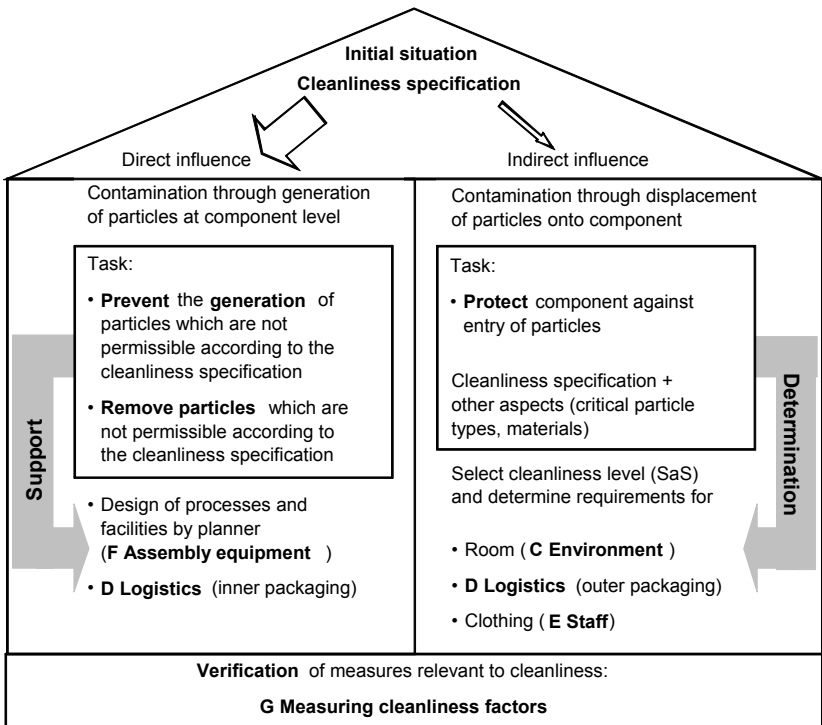


Fig. B.3: Diagrammatic representation of the concept of the guideline. The cleanliness specification is shown as a starting point, followed by direct and indirect influences affecting cleanliness and then the chapters of the guideline which give relevant information and assistance regarding cleanliness tasks and basic procedures for testing cleanliness.

Comment: Deviations from minimum measures and requirements of a cleanliness level as recommended in the guideline are only permitted if it can be proved that the quality target is not affected as a result. The use of measures to achieve a higher cleanliness level is generally associated with increased effort and costs and may not necessarily improve the relevant degree of cleanliness, especially if indirect influencing factors are concerned.

B.3.2 Application

The contents of the guideline can be consulted to plan a new assembly facility and environment as well as to carry out alterations to an existing one:

New planning: the complete contents of the guideline are to be taken into consideration.

Note: If similar products are to be manufactured or similar process steps implemented in the new facility as in the existing one, the existing facility can be analyzed for particle sources using the procedures described in Chapter G: Assessing cleanliness factors and the results implemented in the planning of the new facility.

Alterations: only the relevant sections of the guideline and their contents are to be consulted if alterations are made to an existing assembly facility. However, it must be considered that alterations could influence areas which are not directly affected:

- Relocation: only the altered general conditions caused by the relocation need to be taken into account, e.g. changed environmental conditions or component delivery.
- Alterations to the product: The technical characteristics of a product are altered: processes affected by this need to be considered, e.g. additional or altered assembly processes, altered workpiece receivers, alterations to packaging and feeds, etc.

Alterations to the cleanliness specification (new or intensified): if the assembled aggregate or product does not fulfill the new cleanliness specification despite adequate cleanliness of the single components, the assembly process and environment must be analyzed for particle sources (see **Chapter G: Determination of cleanliness impacts**, Techniques). If the critical particle sources which could lead to the cleanliness specification being exceeded can be identified, the relevant chapters of the guideline can be consulted to optimize specifications or obtain assistance (e.g. packaging abrasion) (see **Chapter D: Logistics**).

- Personnel changes: carrying out training and sensitization measures regarding technical cleanliness.
- Alterations to processes: if process parameters are altered or different processes introduced, it must be assessed whether changes in the amount of particles entering the product or aggregate to be assembled occur. Here, the relevant chapters of the guideline concerned with the altered process apply.

B.3.3 Implementation

Due to the fact that many areas and instances of a company or supplier chain may be affected by cleanliness-relevant measures, at the start of a project a **responsible person** is named who includes and coordinates all other disciplines.

In the process, the system boundary of the project needs to be set, i.e. where considerations start, for example when single components have been cleaned at the supplier's or in-house, on arrival at the assembly facility, etc.

At the start of a cleanliness project, all necessary information must be available, all affected areas included and all requirements fulfilled. In the process, the following questions need to be clarified:

- Is there a cleanliness specification for the single components and aggregates / systems to be assembled? Who determines the cleanliness specifications? Is this included in the project?
- Is the cleanliness specification of all supplied parts adhered to and monitored (who is responsible for cleaning, who carries out the cleanliness analyses when and how)? This is the main requirement for implementing the guideline.
- Are there contact partners for the subject of cleanliness in all affected disciplines?

Note: Further questions regarding the identification of potentials to improve the degree of cleanliness can be found in **Chapter K: Analysis of potentials**.

Three consecutive steps can be taken when designing an assembly facility and environment (see **Sequence Diagram in the annex**):

1. The assembled aggregate or system must already fulfill the cleanliness specification. In order to do this, the assembly line must already be in existence (in the case of cleanliness specifications fixed at a later point in time). If the cleanliness specification is fulfilled, no further measures are required and production can be continued in a conventional assembly facility.
2. If the cleanliness specification after assembly cannot be fulfilled, the possibility of subjecting the assembled system or aggregate to a final cleaning process while maintaining all other quality characteristics must be assessed. It must also be proved that the cleanliness specification can be fulfilled in this way. As in Point 1, production can continue in a conventional assembly facility with the addition of a subsequent cleaning procedure.

3. If the cleanliness specification cannot be fulfilled despite a final cleaning procedure or if a final cleaning procedure is not possible, the process chain can be analyzed to ascertain and eliminate critical particle sources. Within the scope of the system boundary under consideration, all process steps are to be listed and particle counts in the system requiring assembly determined (see **Chapter G: Determination of cleanliness impacts**) via tests and / or expert knowledge. Furthermore, the source responsible for the entry of particles is to be named and weighted. This can be done in the form of a matrix of process steps and potential influences (assembly equipment, assembly environment, logistics and personnel), as shown in Annex 2 - Process Chain Analysis.

This results in an overview of the most critical particle sources which need to be suppressed as part of a process optimization. Assistance can be found in the corresponding chapters of the guideline. The degree of detail of process steps and influencing factors must be selected in such a way to enable critical steps and causes of particle generation to be clearly named.

Note 1: When assessing the entry of particles, not only the resulting quantity of particulate contamination is always to be evaluated but also the degree of risk that it could reach functionally-critical component areas (directly or as a result of displacement). To do this, the functionally-critical areas of a component must be identified (located on the outside or inside of the component) and whether they can be accessed by particles (closed, open or encapsulated components or aggregates).

Note 2: From the considerations in Note 1, varying degrees of cleanliness may be determined for different areas of the assembly facility and environment, especially in cases where the functionally-critical areas are localized or only temporarily unprotected. Furthermore, it may sometimes be sufficient to implement cleanliness-relevant measures or cleanliness levels only for specific time intervals, e.g. when aggregates or systems without cleanliness specifications are produced in the same section of the assembly line but at different times.

Annex A.B

Annex A.B.1 Sequence Diagram: Planning a clean assembly facility

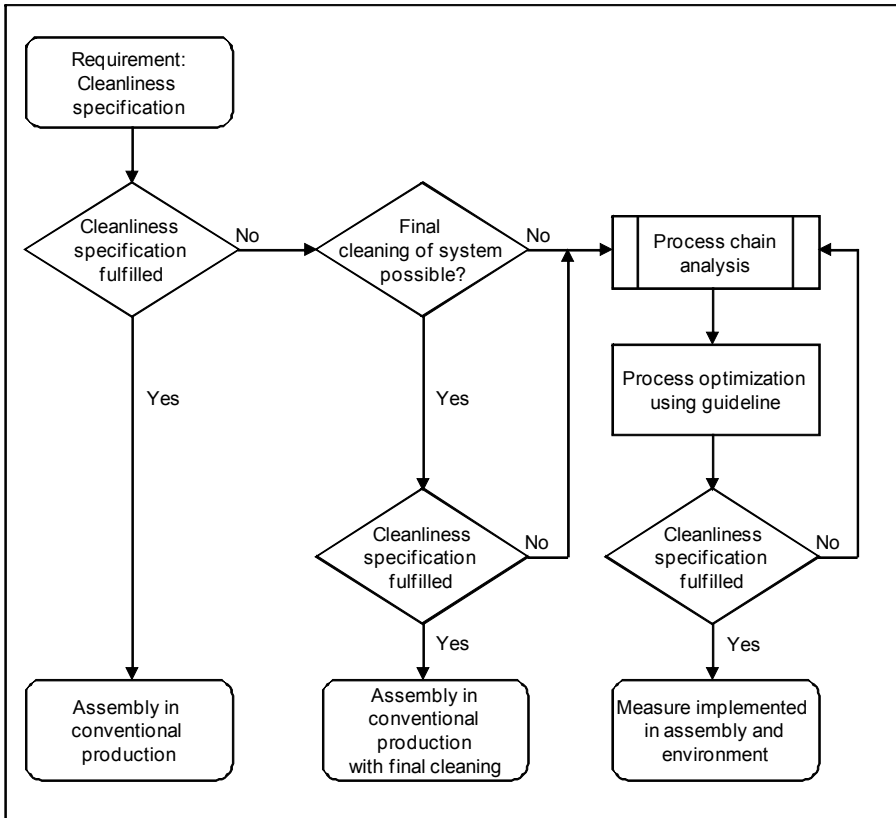


Fig. B.4: Sequence Diagram: Planning a clean assembly facility

Annex A.B.2 Process chain analysis

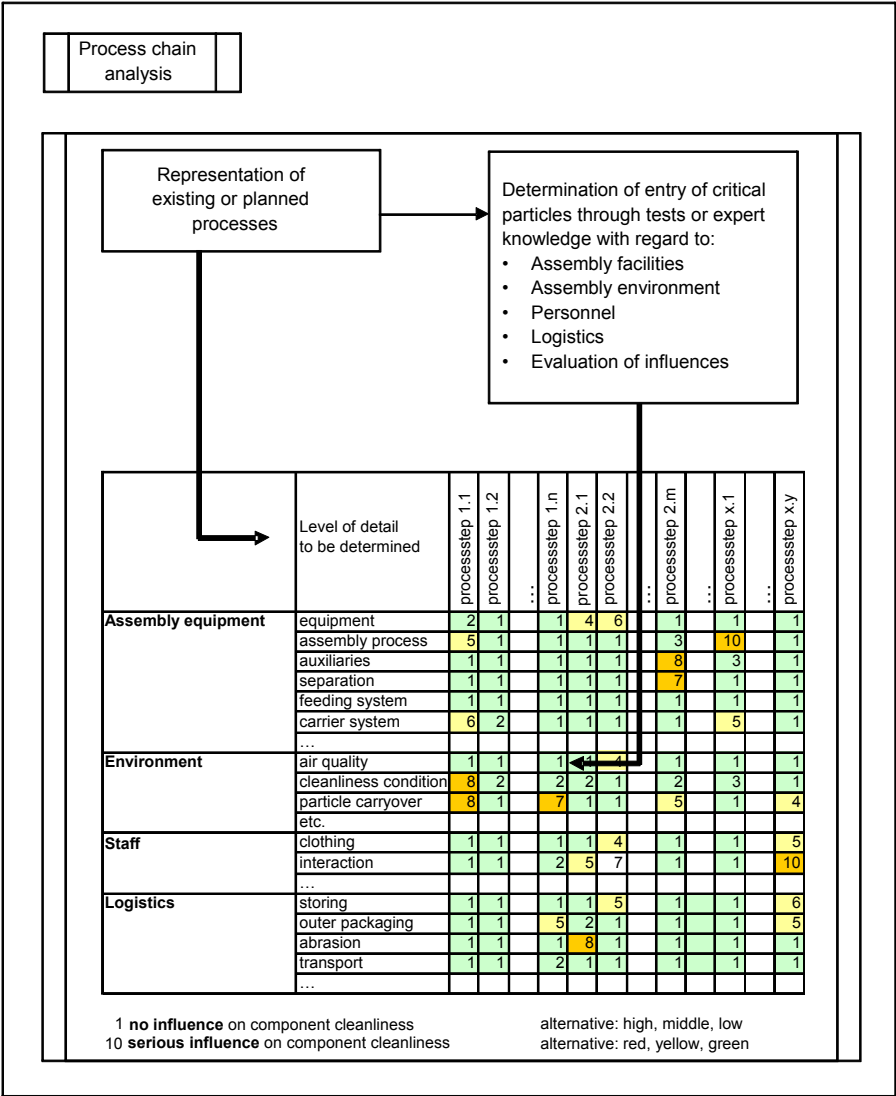


Fig. B.5: Process chain analysis

C: ENVIRONMENT

C.1 Introduction

The term **environment** describes the area which encloses the products and associated processes.

In order to promote and ensure product cleanliness, in all cleanliness-sensitive industries it is standard practice to concentrate measures into defined spatial areas to specifically exclude contamination risks. Especially highly-sensitive products such as semiconductor chips or solutions for medical injection have to be manufactured in **cleanrooms**. This is necessary in order to exclude the entry and spread of tiny particles or micro organisms via the environmental atmosphere. The classification of cleanrooms and clean air zones ends with the maximum particle size of 5 µm / ISO 14644, VDI 2083 /.

Micro particles, which can be controlled using clean air technology, do not currently represent a functional risk as far as many components processed in the automotive industry are concerned. The advantage of an expensive cleanroom installation is doubtful in such cases. Even in the highest quality cleanroom environment, the clean air technology is unable to control compact particles generated, for example, when an assembly facility is in operation or emitted by packaging, which are much larger than 5 µm in size [exception: dispersible fluff released into the environment].

The advantages of a defined spatial environment are not only limited to controlling the environmental atmosphere. Its effect with regard to promoting and stabilizing quality is essentially due to the separation of the environment from areas and sequences which are not as clean, as well as the strict organization of material flows and usage of the area in question.

In order to cover the broad spectrum of cleanliness requirements for automotive components, this main chapter recommends adapted spatial environments in the form of so-called **clean areas** with varying **cleanliness grades** for designing and organizing the **assembly environment**.

The cleanliness grade (CG) describes the way each area should be designed as well as supplementary measures and regulations for clean areas. Adapted, additional recommendations regarding personnel (e.g. clothing), logistics and packaging are also included in the cleanliness grade (see Chapter **D: Logistics** and **E: Personnel**).

A clean area also always represents a specifically-fitted installation for added value which demands that staff, including management staff, is especially sensitized and aware of the aspect of cleanliness.

Techniques for characterizing particle charges in clean areas are described in **Chapter G: Assessing cleanliness factors**.

The validity of the cleanroom standards ISO 14644 and VDI 2083 remains unaffected by the regulations recommended here.

C.2 Fundamentals

The basic function of a clean area is to keep contaminating influences away from uncontrolled areas such as e.g. mechanical processing or incoming deliveries as well as natural environmental influences. This firstly concerns the control and reduction of stray particles in the environmental atmosphere (airborne particles). Through appropriate specifications and measures with regard to personnel and the transfer of materials, it also prevents the entry and internal displacement of contamination.

The internal displacement of contamination to sensitive components and the emission of particles into the environmental atmosphere can also be reduced by ascertaining which materials may be used and rules of conduct apply in a clean area. This is supported by measures for looking after a clean area.

Where applicable, it may also be necessary to adapt additional parameters such as temperature, humidity or percentage of fresh air to the requirements of the clean area.

C.3 Design

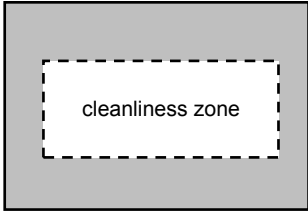
Where appropriate, measures and requirements for the various clean area subgroups are described and classified in the following sections.

C.3.1 Measures and recommendations - constructional

C.3.1.1 Classification of clean areas

Clean areas are created to protect sensitive surfaces and goods. A clean area serves to maintain as best as possible the required degree of cleanliness of components, auxiliary materials and systems during processing. Cleanliness levels of components should not be lowered as a result of environmental influences.

A clean area is an area where the entry of contamination is prevented. Any contamination generated inside it is carefully confined and removed. The design, measures and utilization of clean areas depend upon the cleanliness requirements for the products concerned. The diagram below shows how design and utilization are orientated towards required cleanliness grade.

clean area (in order of rising cleanliness requirements)	symbol / characterization
Cleanliness grade 0 (CG0): uncontrolled zone <ul style="list-style-type: none">▪ Assembly and potentially critical processes (e.g. milling) are located in the same zone▪ No cleanliness-orientated regulation (other than 5S)	(Not characterized)
Cleanliness grade 1 (CG1): cleanliness zone <ul style="list-style-type: none">▪ Zone is separated from potentially critical areas¹⁾ e.g. by<ul style="list-style-type: none">- Floor markings- Partitions- Ceiling curtains▪ Cleanliness-orientated regulation inside the zone▪ Cleanliness-orientated regulation of movements of materials and personnel to adjacent or other zones▪ Standard air-conditioning	

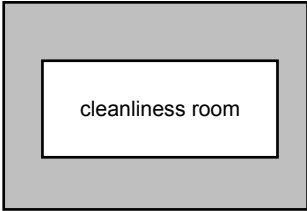
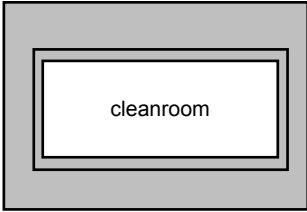
Cleanliness grade 2 (CG2): cleanliness room <ul style="list-style-type: none"> ▪ Fixed constructional separation from other zones¹⁾ ▪ Cleanliness-orientated regulation inside the zone ▪ Cleanliness-orientated regulation of movements of materials and personnel to adjacent or other zones ▪ Standard air-conditioning 	
Cleanliness grade 3 (CG3): cleanroom <ul style="list-style-type: none"> ▪ Fixed constructional separation from other zones ▪ Cleanliness-orientated regulation inside the zone ▪ Cleanliness-orientated regulation of movements of materials and personnel to adjacent or other zones ▪ Fitted with clean air technology ▪ Distinct "room-in-room" system with locks 	
¹⁾ cleanliness zones and cleanliness rooms may be located inside a room which is also used for other purposes; they can however be located in a totally separate room or building.	

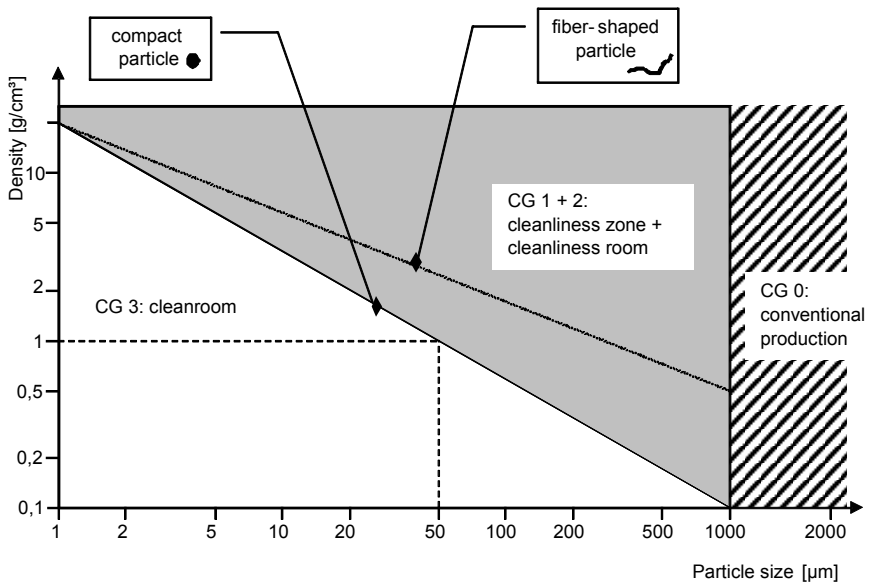
Table C.1: Cleanliness grade orientated towards room concept

Note 1: Errors associated with cleanliness made right at the beginning cannot be compensated for through subsequent alterations even under the best cleanroom conditions (e.g. delivery of cleaned parts in soiled packaging or unreliable component-cleaning processes). However clean a zone may be, handling a component or auxiliary material (e.g. sealing or lubricating agent) in the zone will not make it cleaner than it was before it was brought in.

Note 2: Air-conditioning systems can be used to actively remove dispersible micro particles from the environmental atmosphere, e.g. adapted filter classes, air exchange rates and airflow velocities. The cost and extent of such measures depend upon the sensitivity of products and processes towards micro particles. Macroscopic particles generated during production cannot be avoided or reduced using this method.

C.3.1.2 Selecting the cleanliness grade (CG)

As described in **Chapter B: Designing a clean assembly facility**, cleanliness specifications for the components and aggregates concerned form the basis for selecting the cleanliness grade, which will determine room features and other aspects regarding personnel and logistics. The so-called dispersibility diagram in **Figure C.1** can be consulted to establish a relationship between critical particle sizes and room concepts. The figure illustrates the ability of particles to spread via the environmental atmosphere.



Examples of materials:

$\rho(\text{aluminum})$	= 2.7 g/cm³
$\rho(\text{steel})$	= 7.8 g/cm³
$\rho(\text{polystyrene})$	= 0.02-0.09 g/cm³

Fig. C.1: Airborne particles vs. room concept (dispersibility diagram)

The axes in the diagram represent particle size and particle density; three zones are marked:

- The shaded area with particle sizes above 1000 µm: this is the zone outside cleanliness specifications according to VDA 19, i.e. production can be carried out in a conventional environment without cleanliness-regulating measures – in cleanliness grade 0 (CG0).
- The gray area above the diagonal separating line: particles in this zone primarily follow the force of gravity when they are generated or emitted, i.e. they fall to the ground within a short distance and are not mobile in the environmental atmosphere. Where components or aggregates are functionally-sensitive to such particles, the implementation of clean air technology will not help because critical particles cannot be filtered out of the environmental atmosphere if they are not mobile there. Corresponding manufacturing environments where cleanliness measures are implemented which are not related to clean air technology equate to cleanliness grade CG1 or CG2, i.e. cleanliness zone or cleanliness room.
- The white area below the diagonal separating line: in this zone, particles remain mobile in the air even where airflows are gentle and spread randomly from their point of origin or emission. If a component or aggregate is functionally-sensitive to such particles, the implementation of clean air technology as a supplementary cleanliness-relevant measure may prove effective in filtering such particles out of the environmental atmosphere. A corresponding manufacturing environment equates to cleanliness grade 3 (CG3), i.e. cleanroom.

The dividing line between the gray and white zone - the dispersibility line – is not a distinct boundary and is dependent upon a number of particle and airflow parameters. The following rule generally applies: the lower the size and density of a particle, the higher the risk of it spreading in the environmental atmosphere. Particle shape also plays a major role. As the shape of a particle changes from round or compact to fibrous, the line shifts upwards (dotted line in **Figure C.1**). This causes the size of the zone with cleanliness grade 3 (where cleanroom technology is implemented) to increase in consequence.

Note: On considering the following points, the position of the dispersibility line as a boundary between airborne and rapidly sedimenting particles becomes plausible through three reference points in the curve:

A light draught is enough to cause a polystyrene sphere with a diameter of 1 mm (1000 μm) to move large distances.

A soot particle 50 μm in size with a density of 1g / cm^3 falls in the air at a rate of 10 cm / s and moves laterally about the same distance.

Particles 1 μm in size, even with a high density, are primarily airborne and rarely settle.

Examples:

- If compact particles 500 μm in size or larger are critical to the function of a component or aggregate, the dispersibility diagram shows that a cleanliness zone or cleanliness room (cleanliness grade 1 + 2) is adequate as a manufacturing environment.
- If a cleanliness specification states that metallic particles above 200 μm are critical to a component or aggregate and if, for example, steel (7.8 g / cm^3), aluminum (2.7 g / cm^3) or magnesium (1.7 g / cm^3) are used in production processes, the dispersibility diagram shows that cleanliness grade 1+2 (CG1 + CG2) is required.
- If textile fibers also need to be excluded to fulfill a cleanliness specification, the dispersibility line shifts upwards. Even where particle lengths of 1000 μm may be present, it may make sense to implement clean air technology, i.e. cleanliness grade 3 (CG3).
- If a cleanliness specification states that no particles above 10 μm may be present in the environmental atmosphere, clean air technology with cleanliness grade 3 (CG3) is necessary.

Comparison of environmental concepts:

The comparison shown in Table C.2 illustrates the differences between various environmental concepts with a view towards controlling or confining particle generation. The classification only applies where recommended measures for required cleanliness grades have been implemented.

The limiting value of 5 μm is deliberately shown here to establish a relationship with the upper limit of the standard cleanroom classification. However, as far as the technical cleanliness of functionally-relevant automotive components is concerned, it should not necessarily be concluded that such micro particles must always be considered or eliminated to attain quality targets.

Room concept Contamination risks	conventional environment CG0	cleanliness zone CG1	cleanliness room CG2	Cleanroom CG3
A) Entry of contamination due to displacement via packaging	-	O	+	++
		Supported by defined measures regulating movements of materials and personnel		
B) Entry of contamination due to displacement by personnel	-	O	+	++
		Supported by defined measures regulating movements of materials and personnel		
C) Entry of contamination via air from outside the zone	-	-/O	+	++ ¹⁾
		Supported by separating from uncontrolled zones		
D) Fluff / dust or airborne particles > 5 µm inside the zone	-	-/O	O	+ ²⁾
		Supported by defined measures regulating clothing and materials used		
E) Particles in environmental atmosphere < 5 µm inside the zone	-	-	-	++ ²⁾
F) Slow-moving particles generated by processes	-	-	-	-
1) Supported by positive pressure in room				
2) Supported by filtration of air and airflow guidance to remove generated particles				
Legend: ++ controlled with a high degree of reliability + controlled, O partially controlled, - not controlled				

Table C.2: Room concepts and particle control

The ability of clean areas to confine critical particles is especially due to the factors A), B) and C).

Points 4) and 6) of the classification in Table C.3 are related to the presence of airborne particles in the environmental atmosphere. The possibly strong influence of process-related particle sources cannot be taken into general consideration here.

Relative effort involved in installing and using clean areas					
Room concept Effort / costs		conventional environment	cleanliness zone	cleanliness room	Cleanroom
		CG0	CG1	CG2	SCG3
1.	Space requirement	Low	Low / average	Average	High
2.	Investment costs (constructional)	Low	Low / average	Average	High
3.	Operational costs (air technology)	Low	Low / average	Low / Average	High
4.	Frequency of cleaning exposed surfaces near the product	In compliance with company standard	High	Average	Average / Low
5.	Frequency of cleaning floor area	In compliance with company standard	Low	Average	High (especially in turbulent cleanrooms)
6.	Costs required to protect exposed functional surfaces	Not appropriate	High	Average	Low
7.	Material transfer times (especially entry via locks)	Low	Low / average	Average	High
8.	Personnel transfer times (entering and exiting via locks)	Low	Low	Low / average	High

Table C.3: Clean areas with a view to relative effort and costs involved

Explanations of the various points:

1. CG3 requires more space because of clean air technology systems and locks. A raised floor may need to be installed in low-turbulence cleanroom zones (increased room height requirement). CG1 and CG2 need additional floor space, especially due to barrier zones.
2. Increased costs for CG3, especially due to clean air technology systems.

3. Increased costs for CG3, especially due to clean air technology systems. Costly air-conditioning systems may already be required from CG1 upwards in order to extract heat and humidity from partially / completely closed areas and to supply oxygen to personnel.
4. CG3: the clean air introduced into the room does not increase the particle charge in the room or on the surfaces within. Micro particles set free by the increased air exchange are removed from the area. CG2 has a better barrier function than CG1 as far as airborne particles from adjacent zones are concerned. Also, fewer particles are brought into the room by materials or personnel.
5. With CG3 (especially in zones with a turbulent mixed airflow), the airflow near the floor may stir up micro particles and transport them (back) towards products / processes. Consequently, the floor needs to be cleaned more frequently.
6. The percentage of potentially critical particles in the environmental atmosphere decreases from CG0 to CG3. Requirement: no excessive quantities of particles may be generated in the room.
7. Increases in the direction of CG3 due to the multi-layer principle of packaging and, for example, the need to move goods or clean them in a defined way before bringing them into the room.
8. Mainly due to changing / altering clothes.

Examples of clean areas are shown and described in **Chapter D: Logistics**.

C.3.1.3 Localized clean areas

Where possible, particle-generating processes inside the clean area are to be eliminated (e.g. through encapsulation, possibly combined with targeted suction-cleaning).

If necessary, localized installations are only (or additionally) used in a clean area to confine particles.

MEASURES (IN ORDER OF INCREASING CLEANLINESS REQUIREMENTS)	
A)	Encapsulation of facilities, feeding systems, goods buffers and / or workstations 1) to screen: <ul style="list-style-type: none"> - To the side or above - To the side and above
B)	As in A) but with the use of localized clean air technology 2) (e.g. clean workbench as workstation or FFU [filter Fan Unit] at the level of an assembly station)
<p>¹⁾ Through encapsulation (e.g. Perspex housing), airborne particles from the environmental atmosphere can be contained. However, particles generated inside the encapsulation may accumulate due to their inability to disperse. The benefit of such a measure must be assessed individually.</p> <p>²⁾ The forced airflow may enable dispersible particles generated (e.g. by mechanical abrasion) inside the encapsulation to be removed. However, an unfavorable airflow may produce the opposite effect with the result that generated particles are transported towards functional surfaces.</p> <p>In both cases, if the environmental atmosphere contains critical particles, care is to be taken to ensure that sensitive surfaces outside localized clean areas are kept well protected.</p>	

Tabelle C.4: Methods of localized particle containment

If a worker disturbs an encapsulated device (e.g. opens a system in case of malfunction or for refitting), particles may be transferred from the external unprotected environment to the interior.

A further localized measure is to install suction-cleaning equipment to remove particles at source. The fact that incoming air may also be charged with critical particles must be taken into consideration in the design.

For more information, see **Chapter F: Assembly equipment**

C.3.1.4 Layout

When designing a clean area, among other things, the following aspects require consideration from the point of view of controlling critical contamination:

1. Easy-to-clean work environment
2. The location of e.g. incoming / outgoing goods, storage areas, material buffers, pre-assembly stations and refinishing stations
3. Position and distance away from doors, gates, windows, personnel and machine pathways
4. Location of particle-generating processes inside the clean area, e.g. welding, soldering, chipping
5. Location of processes especially sensitive to particles; e.g. bonding, oiling seals, application of sealing agents
6. Suitable transfer points / gates between zones for materials and personnel; e.g. separate locks for goods and personnel in the case of a cleanroom
7. Separation of material flows; e.g. single components / aggregates and clean / contaminated parts inc. the associated movement of goods carriers
8. Possible use of cleaning facilities as locks in the clean area
9. If appropriate: position of cleaning stations integrated into the process sequence of the assembly facility (e.g. suction-cleaning systems for con rods or workpiece carriers)

C.3.1.5 Materials and surfaces

To minimize the accumulation and emission of particles, the following properties are to be considered when selecting materials:

- Resistance to abrasion
- Surface roughness / porosity
- Chemical resistance to process fluids and cleaning agents
- Conductivity / electrostatics ¹⁾
- Magnetism ¹⁾

¹⁾ Particles may adhere more strongly to surfaces

Criteria and measures:

- Where possible, painted surfaces are to be avoided (wear causes surfaces to give off paint particles).
- Electrostatic charging may lead to the increased accumulation of particles on surfaces.
→ Remedy, e.g. use conductive materials or ionization units to counteract charges.
- Wall elements standing on floors must be made of a highly shockproof and abrasion-resistant material, especially in zones where materials are frequently delivered and dispatched.
→ By installing panels in specific places, assembly equipment housings can be protected against mechanical damage and wear.

Note: Stainless steel is the preferred material in cleanliness technology.

Magnetic components and equipment may increase the risk of contamination of ferromagnetic particles from the environment. Certain processes such as electron beam welding, for example, may be directly affected. More information regarding considerations can be found in **Chapter F: Assembly equipment**.

C.3.1.6 Floors, ceilings and walls

The floors, ceilings and walls in clean areas are to be planned and constructed in such a way so that surfaces are easily accessible.

Steps, protrusions and holes are to be avoided. In the case of floor / wall and wall / wall connections, corners and joins should be rounded to facilitate cleaning.

Wall elements need to be made of especially shockproof and abrasion-resistant materials, especially near forklift vehicle, transport cart and carrier pathways. Locally mounted stainless steel panels may protect wall areas in specific places against mechanical damage or wear. Floors must be anti-slip.

Note: In areas where oils, greases or other fluids may precipitate, flooring may not become slippery; e.g. use additional floor mats.

Floor areas					
Measure (in order of increasing cleanliness requirements)		grade 0	grade 1 cleanliness zone	grade 2 cleanliness room	grade 3 Cleanroom
1.	Wooden flooring	+	-	-	-
2.	Rough, damaged industrial screed floor	+	-	-	-
3.	As in 2) but undamaged	+	+	-	-
4.	Sealed with synthetic material	o	+	+	+
5.	Cleanroom-suitable flooring	o	o	o/+	+
6.	Tack mats at entrances	-	-	o/+	+
Legend: + = suitable - = unsuitable o = not required					

Table C.5: Concepts for floors

When selecting a type of flooring, properties such as chemical resistance (e.g. to oils), mechanical resistance and ESD protection are to be taken into account. Unsuitable floor-care products may lastingly impair conductive properties.

Mechanical wear due to the movement of materials can be reduced by placing goods on roll carts or racks with rollers and by not putting containers on floors.

Ceiling areas					
Measure (in order of increasing cleanliness requirements)		grade 0	grade 1 cleanliness zone	grade 2 cleanliness room	grade 3 Cleanroom
1.	<u>Exposed</u> ceiling, e.g. with metal grid walkways, visible supply technology and skylights	+	-	-	-
2.	Ceiling / false ceiling (suspended or supported) not made of abrasion-resistant material ¹⁾	o	+	-	-
3.	Ceiling / false ceiling (suspended or supported) made of abrasion-resistant material ²⁾	o	o	+	+

Ceiling areas					
Measure (in order of increasing cleanliness requirements)		grade 0	grade 1 cleanliness zone	grade 2 cleanliness room	grade 3 Cleanroom
4.	Cleanroom-suitable ceiling elements	o	o	o	+
Legende: + = suitable - = unsuitable o = not required					
¹⁾ e.g.: Lime, plaster, concrete, wood (unpainted), plasterboard ²⁾ e.g.: Wood (painted / coated), stainless steel, coated metals, plastics (age-resistant), glass					

Table C.6: Concepts for ceilings

Note 1: It may be necessary to walk on ceiling constructions

Note 2: Ceiling lights are to be designed so that no dust may settle on them (e.g. recessed in the ceiling behind glass, or sealed mounted elements).

Wall areas					
Measure (in order of increasing cleanliness requirements)		grade 0	grade 1 cleanliness zone	grade 2 cleanliness room	grade 3 Cleanroom
1.	Porous walls / wall elements; not abrasion-resistant ¹⁾	+	-	-	-
2.	Walls / wall elements; abrasion-resistant ²⁾	o	+	+	+
3.	Cleanroom-suitable wall elements	o	o	o	+
Legend: + = suitable - = unsuitable o = not required					
¹⁾ e.g.: Lime, plaster, concrete, wood (unpainted), plasterboard ²⁾ e.g.: Wood (painted / coated), stainless steel, coated metals, plastics (age-resistant), glass					

Table C.7: Concepts for walls

Note: Locally mounted stainless steel panels protect specific wall areas against mechanical damage or wear (e.g. due to transport carts).

C.3.1.7 Doors, gates, locks, entrances, windows

To reduce disturbing influences (e.g. drafts or entry of outside air), the following are recommended:

1. Always keep skylights and windows closed (locks can be put on windows if required)
2. Only open and close doors as required (not to air rooms)
3. Fix automatic closing systems to doors / gates
4. Install air curtains at doors and / or gates
5. Fit locking systems to prevent doors / gates from being opened at the same time
6. Install gates and doors, for example, as double gates / doors (lock function)

C.3.1.8 Pathways and storage areas

The following are recommended:

1. Ensure adequate distances between open assembly processes / open carriers and critical or uncontrolled zones (e.g. cutting processes) as well as windows, doors, gates and pathways.
2. If there is a risk of contamination from the environment, sensitive goods are to be wrapped up, covered or sealed to protect them, especially if routine processing is interrupted.
3. Transport pathways and stations with high particle levels are to be cleaned at frequent intervals
4. Transport tasks – especially involving forklift vehicles – are to be kept to a minimum.

C.3.1.9 Supply technology / installations

Where possible, supply technology should be installed in false ceilings and walls (suspended or supported ceilings).

Where feasible, supply technology installed inside rooms should have as few horizontal surfaces as possible and be mounted vertically.

Ceiling lights are to be designed so that no dust may settle on them (e.g. recessed behind glass in the ceiling or as sealed mounted elements).