Cleanroom Validation
cleanroom applications

- laboratories ↔ production environments
- laminar flow boxes ↔ cleanroom concepts

- microelectronics
- pharmaceutical industry, food industry
- nuclear industry, aerospace
- polymer industry
- surgery rooms → initiation!
**cleanroom applications**

- laboratories \(\leftrightarrow\) production environments
- laminar flow boxes \(\leftrightarrow\) cleanroom concepts
- microelectronics
- pharmaceutical industry, food industry
- nuclear industry, aerospace
- polymer industry
- surgery rooms \(\rightarrow\) *initiation!*

![Cleanroom cabinet](http://www.grc.nasa.gov/WWW/ictd/content/labmicrofab.html)

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* cleanup! *magic* in \(\rightarrow\) polymers! *initiation*! *production* 

Krauss Maffei Technologies GmbH

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cleanroom design

- main objective: reduction of particle number concentrations at sensitive environments
- air conditioning (temperature, pressure, humidity) + air filtration (HEPA)
- human operator: **major particle source** → special cloths, tools, moving procedures
  → smoking prohibited 2h before working starts
- separation of different working areas with different cleanroom requirements
- special locking rooms for operators and materials

 definition of a cleanroom
 according to ISO 14644:

A cleanroom is an area set apart by a wall or similar partition, whose degree of cleanliness is achieved by purified air ventilation. Cleanroom environment is pressurized to outside area.
cleanroom design

hospital:
- cleanroom design
  - microelectronics:

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**cleanroom design**

- turbulent dilution flow
  - high flow rate of filtered air
  - continuous dilution of particle concentration
  - for class 1,000 to 100,000

- unidirectional laminar flow
  - vertical flow direction
  - filtered air circulation
  - for class 0.1 to 100
- **cleanroom design**

  - laminar flow box / safety cabinets
  - working places with clean room conditions, especially for laboratory use
  - economic option to a cleanroom facility
  - according to EN 12469 standard
### cleanroom standards

- to setup and operate a cleanroom particle measurements are obligatory
- from these measurements a cleanroom classification is done according to a related standard

<table>
<thead>
<tr>
<th>industry</th>
<th>contamination</th>
<th>standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microelectronics</td>
<td>particles</td>
<td>US Fed 209E → <strong>ISO 14644</strong></td>
</tr>
<tr>
<td>Aerospace</td>
<td>particles</td>
<td>ECSS-Q-ST-70-01</td>
</tr>
<tr>
<td>Food industry</td>
<td>microorganism</td>
<td>VDI 2083</td>
</tr>
<tr>
<td>Pharmaceutical industry</td>
<td>bacteria count</td>
<td>EG-GMP Annex 1</td>
</tr>
</tbody>
</table>

**ISO 14644**: most relevant standard: **“cleanrooms and associated controlled environment”**

Cleanrooms and associated controlled environments provide for the control of airborne particulate contamination to levels appropriate for accomplishing contamination-sensitive activities. Products and processes that benefit from the control of airborne contamination include aerospace, microelectronics, pharmaceuticals, medical devices, healthcare, food and others. Many factors besides airborne particulate cleanliness should be considered in the design, specification, operation and control of cleanrooms and other controlled environments.

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**cleanroom standards**

- **ISO 14644**: most relevant standard: “cleanrooms and associated controlled environment”

  *Part 1: Classification of air cleanliness*
  
  by number concentration (particle/m³) of airborne particles.
  
  Annex B describes test method, using an optical particle counter DPC (discrete particle counter)

  *Part 2: Specifications for testing and monitoring to prove continued compliance with ISO 14644-1*
  
  defines test procedure and validation intervals (6 months ≤ ISO5, 12 months >ISO5)

  *Part 3: Test methods*
  
  describes different performance tests

  *Part 4: Design, construction and start-up*

  *Part 5: Operations*

  *Part 7: Separative devices (clean air hoods, gloveboxes, isolators and mini-environments)*

  *Part 8: Classification of airborne molecular contamination*
**cleanroom standards**

- **ISO 14644**: most relevant standard: *“cleanrooms and associated controlled environment”*

*Part 1: Classification of air cleanliness*

- cleanroom classes: particle number concentrations vs. particle size
- ISO 3: max. 35 particles/m³ ≥ 0,5µm

<table>
<thead>
<tr>
<th>US FED 209E</th>
<th>ISO classification number (N)</th>
<th>Maximum concentration limits (particles/m³ of air) for particles equal to and larger than the considered sizes shown below (concentration limits are calculated in accordance with equation (1) in 3.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ISO Class 1</td>
<td>0,1 µm</td>
</tr>
<tr>
<td>1</td>
<td>ISO Class 1</td>
<td>10</td>
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<td>10</td>
<td>ISO Class 2</td>
<td>100</td>
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<tr>
<td>100</td>
<td>ISO Class 3</td>
<td>1000</td>
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<td>1,000</td>
<td>ISO Class 4</td>
<td>10000</td>
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<td>10,000</td>
<td>ISO Class 5</td>
<td>100000</td>
</tr>
<tr>
<td>100,000</td>
<td>ISO Class 6</td>
<td>1000000</td>
</tr>
<tr>
<td></td>
<td>ISO Class 7</td>
<td>352000</td>
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<tr>
<td></td>
<td>ISO Class 8</td>
<td>3520000</td>
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<tr>
<td></td>
<td>ISO Class 9</td>
<td>3520000</td>
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</table>

ISO 14644-1: cleanroom classes
**cleanroom standards**

**AMD microelectronics:**

### Production Plants

<table>
<thead>
<tr>
<th>Sitz</th>
<th>Wafergröße</th>
<th>Derzeitige Produkt-Entwicklungsregeln</th>
<th>Reinräumen</th>
<th>Kapazität (Wafer pro Woche)</th>
<th>Reinarium Sq. Ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunnyvale, Kalifornien</td>
<td>8 Zoll</td>
<td>0,13 Mikrometer</td>
<td>Klasse 1</td>
<td>600</td>
<td>42500</td>
</tr>
<tr>
<td>SDC (Fab 17)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austin, Texas</td>
<td>6 Zoll</td>
<td>0,7 Mikrometer</td>
<td>Klasse 10</td>
<td>5000+</td>
<td>über 40000</td>
</tr>
<tr>
<td>Fab 14/15</td>
<td>8 Zoll</td>
<td>0,18 Mikrometer</td>
<td>Klasse 1</td>
<td>5000</td>
<td>120000</td>
</tr>
<tr>
<td>Fab 25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dresden</td>
<td>8 Zoll</td>
<td>0,13 Mikrometer</td>
<td>Klasse T100</td>
<td>5000</td>
<td>150000</td>
</tr>
<tr>
<td>Fab 30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aizu-Wakamatsu, Japan</td>
<td>8 Zoll</td>
<td>0,23 Mikrometer</td>
<td>Klasse 1</td>
<td>5000+</td>
<td>70000</td>
</tr>
<tr>
<td>Spansion I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Spansion II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

### Testing, Assembly

<table>
<thead>
<tr>
<th>Sitz</th>
<th>Aktivität</th>
<th>Reinraum</th>
<th>Kapazität (Einheiten pro Woche)</th>
<th>Gesamtfäche.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangkok, Thailand*</td>
<td>Prüfung und Montage</td>
<td>Klasse 1000</td>
<td>7 Millionen</td>
<td>178411</td>
</tr>
<tr>
<td>Singapur*</td>
<td>Prüfung, Fehleranalyse, Geräteanalyse</td>
<td>Klasse 1000</td>
<td>1,8 Millionen</td>
<td>202500</td>
</tr>
<tr>
<td>Penang, Malaysia*</td>
<td>Entwicklung, Prüfung und Montage</td>
<td>Klasse 100</td>
<td>8 Millionen</td>
<td>500000</td>
</tr>
<tr>
<td>Suzhou, China</td>
<td>Prüfung und Montage</td>
<td>Klasse 100</td>
<td>1,9 Millionen</td>
<td>202762</td>
</tr>
</tbody>
</table>

US FED 209E = class 1

→ max. 10 #/m³ ≥ 0,1µm

US FED 209E = class 1000

→ max. 10.000 #/m³ ≥ 0,1µm
steps of cleanroom specification, design, qualification

1. User Requirement Specification (URS) by User

2. Cleanroom and Facility Design by Cleanroom Engineer

3. Design Qualification (DQ) = Commissioning – Procurement

4. Installation Qualification (IQ) = Commissioning – Installation and Testing

5. Operation Qualification (OQ) = Commissioning – Certification

6. Performance Qualification (PQ) = Compliance to Room Data Sheet

7. Cleaning Validation
- **design qualification (DQ)**
  - to confirm that the designs fit the user required specification
    - specifications
    - purchase orders
    - suppliers proposal documents
    - layouts
    - P&ID/flow sheets
    - contractor strategy / interfaces

- **installation qualification (IQ)**
  - to demonstrate that the item as installed, conforms to the design specifications
    - HVAC and other critical instruments are still in calibration
    - equipment specifications, drawings, operation and maintenance manuals
    - installation check of critical components
    - critical component P&ID flow scheme and loop check
    - testing and balancing report
    - HEPA filter integrity testing data review
• **operation qualification (OQ)**
  - to demonstrate that the cleanroom can be operated in conformance to the design specification
    - HVAC and other critical instruments are still in calibration
    - testing of critical alarms and interlocks
    - list of critical operating parameters encompassed by room data sheet
    - testing for the specifications detailed in the room data sheet
    - standard operation protocol for HVAC system controls
    - cleanroom operation protocols for cleanroom operations

• **performance qualification (PQ)**
  - to demonstrate that the cleanroom can reliably perform according to the design specification
    - **monitoring and testing for particulate levels** *(surface and airborne)*
    - **static particulate monitoring**
    - static microbial monitoring
    - **dynamic particulate monitoring** *(sterile areas, in operation)*
    - room data sheet is the cleanroom user required specification
• **performance qualification (PQ)**
  - measurement of air conditions (humidity, temperature)
  - measurement of static pressure

• **Filter integrity testing**
  - *upstream aerosol generation:* adjustment of aerosol concentration to the nominal filter class and the coincidence concentration of the downstream particle counter
  - *upstream particle measurement:* using optical particle counter + dilution system
  - *downstream scanning of the filter:* using an isokinetic sampling probe + optical particle counter

• determination of air replacement number

• **Recovery test**
  - generation of test aerosol inside the cleanroom
  - time measurement to reach 1% of the original generated aerosol concentration

• **visualization of unidirectional laminar flow profile using a fog or aerosol generator**
  - spatial air velocity distribution below air outlet
  - determination of flow direction at working space
Topas cleanroom validation equipment

- complete equipment for particulate monitoring, filter integrity testing and recovery tests

- Aerosol Generator **ATM 226**  
  \[upstream\] \textit{particle generation}

- Dilution System **DIL 554**  
  \[upstream\] \textit{particle measurement}

- Optical Particle Counter **LAP 340**  
  \[up-/downstream\] \textit{particle measurement}

- Isokinetic Sampling Probe **SYS 529**  
  \[downstream\] \textit{particle measurement}
Topas cleanroom validation equipment

- Aerosol Generator ATM 226 → *upstream particle generation*
  - atomizer aerosol generator
  - adjustable particle production rate
  - reliable long-term particle production
  - designed for mobile use
  - internal compressor, no compressed air required
  - integrated mains adapter 100 … 240 VAC
  - stainless steel housing
  - designed for clean room applications

- DEHS as a standard test liquid

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate</td>
<td>max. 300 l/h</td>
</tr>
<tr>
<td>Temperature range</td>
<td>10°C ... 30°C</td>
</tr>
<tr>
<td>Max. counter pressure</td>
<td>20 kPa (0.2 bar)</td>
</tr>
<tr>
<td>Opening pressure of the safety relief valve</td>
<td>max. 90 kPa (0.9 bar)</td>
</tr>
<tr>
<td>Aerosol substances</td>
<td>DEHS, DOP, Emery 3004 (PAO), Paraffine oil, PSL, Salt solutions</td>
</tr>
<tr>
<td>Filling amount</td>
<td>min. 10 ml, max. 80 ml</td>
</tr>
<tr>
<td>Total number concentration</td>
<td>&gt;10^5 particles/cm³</td>
</tr>
<tr>
<td>Mode value</td>
<td>0.25 µm</td>
</tr>
<tr>
<td>Mass flow rate</td>
<td>2.5 g/h</td>
</tr>
<tr>
<td>Max. continuous operation time</td>
<td>≈ 25 h</td>
</tr>
<tr>
<td>Aerosol outlet</td>
<td>Quick connector, 28 mm</td>
</tr>
<tr>
<td>Device fuse</td>
<td>fuse 25x20 - 2A fast-acting</td>
</tr>
<tr>
<td>Power supply</td>
<td>100...240 VAC</td>
</tr>
<tr>
<td>Dimensions</td>
<td>300 x 120 x 195 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>4.8 kg</td>
</tr>
</tbody>
</table>

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Topas cleanroom validation equipment

- Aerosol Generator ATM 226 → *upstream particle generation*
  - adjustable particle production rate
  - adjustable generator flow rate for different nominal facility flow rates
  - different concentrations to test at different filter classes (HEPA, ULPA)

<table>
<thead>
<tr>
<th>Flow rate Equipment, m³/h</th>
<th>Flow rate ATM 300 x 10⁶ Particle/m³ l/h</th>
<th>Flow rate ATM 400 x 10⁶ Particle/m³ l/h</th>
<th>Flow rate ATM 1000 x 10⁶ Particle/m³ l/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>91</td>
<td>92</td>
<td>98</td>
</tr>
<tr>
<td>100</td>
<td>94</td>
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<td>200</td>
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<td>104</td>
<td>128</td>
</tr>
<tr>
<td>300</td>
<td>105</td>
<td>111</td>
<td>150</td>
</tr>
<tr>
<td>600</td>
<td>123</td>
<td>136</td>
<td>226</td>
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<tr>
<td>700</td>
<td>130</td>
<td>145</td>
<td>259</td>
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<tr>
<td>800</td>
<td>136</td>
<td>154</td>
<td>296</td>
</tr>
<tr>
<td>900</td>
<td>143</td>
<td>164</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>150</td>
<td>173</td>
<td></td>
</tr>
<tr>
<td>1200</td>
<td>164</td>
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<td>1500</td>
<td>186</td>
<td>226</td>
<td></td>
</tr>
<tr>
<td>1600</td>
<td>193</td>
<td>237</td>
<td></td>
</tr>
<tr>
<td>1800</td>
<td>209</td>
<td>267</td>
<td></td>
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<tr>
<td>1900</td>
<td>217</td>
<td>281</td>
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<tr>
<td>2000</td>
<td>226</td>
<td>296</td>
<td></td>
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<tr>
<td>2200</td>
<td>243</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2500</td>
<td>278</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2800</td>
<td>311</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Topas cleanroom validation equipment**

- **Dilution System DIL 554** → *upstream particle measurement*
  - required to avoid coincidence errors at the upstream particle counter
  - "closed" dilution system
    - no compressed air required
    - no contaminated exhaust air flow to the cleanroom
    - small pressure drop
  - continuous internal monitoring of dilution ratio (1:100)
  - cascading several units for higher dilution ratio
  - models for 1cfm or 2cfm particle counters
  - high HEPA filter capacity (30g)
  - designed for mobile use
  - battery operated
  - stainless steel housing

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Topas cleanroom validation equipment

Optical Particle Counter LAP 340 → up-/downstream particle measurement

- 90° light scattering, counting and sizing of discrete airborne particles
- designed for mobile use
- ISO 14644: photometer vs. particle counter
- advantages of using a particle counter:
  - much smaller upstream concentrations
  - less filter contamination
  - much more sensitive to detect smaller leaks
- probes: temperature, relative humidity, air velocity, Δp
- PC interface for remote control

Flow rate: 1 cfm / 28,3 lpm
Measuring range: 0,2\(^1\).. 10 μm
Size channels: 16
Max. concentration: 35 P/cm\(^2\) \(^2\)
Measuring time: 1 s ... 99 h
Measuring modes: single, continuous

\(^1\) 50% counting efficiency
\(^2\) 7,8% coincidence error
Topas cleanroom validation equipment

- **Isokinetic Sampling Probe SYS 529 → downstream particle measurement**
  - determination of potential leaks from a filter leakage scan test
  - validation of each potential leak by a static measurement
  - isokinetic sampling: sampling with a constant air velocity
  - $0.45 \text{ m/s} @ 1\text{fcm}$ relates to $1620 \text{ (m³/h)/m²}$ specific air volume
  - accepted tolerance: $\pm 20\%$
  - rectangular shape $15\times80 \text{ mm}$ -> exact scanning of filter edges
  - design / dimensions according to ISO 14644-3

![Diagrams of circular and rectangular probes](image)

<table>
<thead>
<tr>
<th>Cleanroom Classes</th>
<th>Specific Air Volume $\text{m³/h/m²}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 100.000</td>
<td>turbulent</td>
</tr>
<tr>
<td>Class 10.000</td>
<td>turbulent</td>
</tr>
<tr>
<td>Class 1.000</td>
<td>turbulent</td>
</tr>
<tr>
<td>Class 100</td>
<td>laminar</td>
</tr>
<tr>
<td>Class 10</td>
<td>laminar</td>
</tr>
<tr>
<td>Class 1</td>
<td>laminar</td>
</tr>
<tr>
<td>Class 0.1</td>
<td>laminar</td>
</tr>
</tbody>
</table>

Scan rate $v_{probe} < 8\text{ cm/s}$
Topas cleanroom validation equipment

- Installation and connection of all instruments
- starting up the ATM 226, adjusting required upstream concentration (> 10⁶#/cf)
- upstream concentration measurement, 3x1min
- switching the particle counter to the downstream side, zero counting efficiency
- downstream leak scanning test

\[
C_{\text{upstream}} = \frac{\dot{N}_{\text{ATM}}}{V_{\text{total}}} = \frac{c_{\text{ATM}} \cdot \dot{V}_{\text{ATM}}}{\dot{V}_{\text{box}} + \dot{V}_{\text{ATM}}} = \frac{10^{13} \text{ P} / \text{m}^3 \cdot 0,1 \text{ m}^3 / \text{h}}{1000 \text{ m}^3 / \text{h} + 0,1 \text{ m}^3 / \text{h}}
\]

\[= 1000 \text{ P} / \text{cm}^3\]

\[= 10 \text{ P} / \text{cm}^3 \quad (1:100 \text{ diluted})\]

\[c_{\text{ATM}}(>0,1\mu\text{m}@100l/h) = 10^7 \text{ P} / \text{cm}^3\]

coincidence concentration of the particle counter: 35 P/cm³

H14 filter: 99,995%

\[C_{\text{downstream}} = 0,05 \text{ P/cm}^3 = 1415 \text{ P/cf}\]
test software CRQWin

- Topas in-house development
- in close cooperation with cleanroom service companies to meet their requirements
- **documented & retraceable** cleanroom validation according to ISO 14644, EG-GMP Guideline

**Basic protocol data:** date of validation, facility operator, facility identification, service company
test software CRQWin

- cleanroom specifications: validated room of a facility, room dimension, operation mode at test
- nominal cleanroom classification,
- specifications of the flow conditions, used HEPA filters
- specification of integrated laminar flow boxes
test software CRQWin

- used equipment: models of aerosol generator, dilution system, optical particle counter
- serial number and calibration data of each instrument
**test software CRQWin**

- **cleanroom class validation:** particle counts at different measuring positions
  average values, standard deviation, 95% confidence interval
  confirmation of the nominal cleanroom class

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**Reinraum-Qualifizierung nach ISO14644**

**Mittelwerte der Anzahl Partikelgrößen, bezogen auf 1 Kubikmeter**

<table>
<thead>
<tr>
<th>Messposition</th>
<th>MP1</th>
<th>MP2</th>
<th>MP3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partikelzahl &gt; 0,5 μm</td>
<td>561285</td>
<td>503749</td>
<td>503474</td>
</tr>
<tr>
<td>Partikelzahl &gt; 5 μm</td>
<td>113816</td>
<td>74429</td>
<td>123015</td>
</tr>
</tbody>
</table>

**Berechnung der oberen Vertrauensgrenze (UCL)**

<table>
<thead>
<tr>
<th>Partikelgröße</th>
<th>&gt;0,3μm</th>
<th>&gt;0,5μm</th>
<th>&gt;1,0μm</th>
<th>&gt;5,0μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gesamt-Mittelwert der Messpositionen in [cm³/s]</td>
<td>15755</td>
<td>15755</td>
<td>10479</td>
<td>2340</td>
</tr>
<tr>
<td>Standardabweichung</td>
<td>1286</td>
<td>1286</td>
<td>1161</td>
<td>732</td>
</tr>
<tr>
<td>Vertrauensbereich 95% (UCL)</td>
<td>1654800</td>
<td>1654800</td>
<td>1348944</td>
<td>536336</td>
</tr>
<tr>
<td>Reinraumklasse</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
test software CRQWin

recovery test: time dependent static particle measurement after short-term particle contamination of the cleanroom by an aerosol generator
Topas cleanroom validation equipment

Condensation Fog Generator CFG 290 → *flow visualization* → prototype status

- visualisation of flow profiles
- leakage detection of filters
- leakage detection of cleanroom facilities, e.g. doors
- evaporation of a special test liquid at 300°C
- rapid condensation when leaving the generator
- low impulse, no effect on existing cleanroom flow profile
- dense fog, long lifetime
- sterile, non-toxic, oil-free fog
- designed for mobile use, battery operated

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid reservoir</td>
<td>80 ml</td>
</tr>
<tr>
<td>Liquid mass flow</td>
<td>1.5 ml/min</td>
</tr>
<tr>
<td>Power supply</td>
<td>LiPo Akku; 11.2 V, 2.1 Ah</td>
</tr>
<tr>
<td>Dimensions</td>
<td>300(700)x70x70 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>1.2 kg</td>
</tr>
</tbody>
</table>

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reference customers

- cleanroom environment & pharmaceutical / semiconductor industry
  - ABB ● ASM ● BAXTER ● BAYER ● BÖHRINGER INGELHEIM ● BROOKS ● FELCON ● GM PHARMA ● LSMW ● INFINEON ● MERCK ● M+W ZANDER ● NOVOSIS ● PHARMASERV ● QUIMONDA ● SCHERING ● SOPHARMA ● SERUMWERK DRESDEN ● THERMO ELECTRON ● TYCO HEALTHCARE ● VETTER ● W.H. MAHL ●

- cleanroom consultants, service companies
  - C-TEC ● CAS ● CCI VON KAHLDEN ● CLEANTECH SERVICES ● CLINIX ● DOHM PHARMACEUTICAL ENGINEERING ● INTEGRA ● REUTEC ● SG-PLANUNG ● SKAN AG ● SOPHARMA ●

- instrumentation for research&development, suppliers
  - BOSCH ● BCR ● CAMFIL-FARR ● CCS ● DAIMLER-CRYSLER ● DEHA ● DELBAG ● DUPONT ● FERRING ● FESTO ● FREUDENBERG ● ELECTROLUX ● GRIMM ● GSF ● KENDRO HERAUS ● KANOMAX ● KLOTZ ● LAVISION ● LIGHTHOUSE ● LUWA ● MAHLE ● MANNESMANN ● MANN+HUMMEL ● MIELE ● MCLoud RUSSEL ● MEASURETRONIX ● PMS ● PHILIPS RESEARCH ● RIENSCH&HELD ● TESTO ● TSI ● VORWERK ●