



Evaluation of Surface Particle Deposition in Data Centers

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Study Info

Anonymized study
One-week field study

Sampling Period

Seven to eight days

Key Terms

- Surface particle deposition
- Gravimetric analysis
- Visible particle counts
- Microscopy and image analysis

Key Guidance Documents

- ISO 14644-3:2019 Cleanrooms and associated controlled environments – Part 3: Test methods
- ISO 14644-17:2021 Cleanrooms and associated controlled environments – Part 17: Particle deposition rate applications

Purpose: the client asked ARE Labs to measure the rate at which airborne particles settle onto horizontal surfaces in two data-center buildings, B1 and B2, at client-selected floor, goalpost and plenum positions, and to characterize the size and appearance of the settled material.

Methods: ARE Labs prepared and pre-weighed glass collection slides in capped holders, shipped them to the site, and received them back after a seven- to eight-day exposure period. Each slide was weighed in duplicate before and after exposure, examined for visible coarse particles, and studied by calibrated microscopy at two magnifications. Image analysis described the retained objects.

Results: Of 126 exposed slides, 123 formed the primary data set. Overall means were 14.7 mg/m²/day for mass and 2,090 particles/m²/day for visible coarse-particle deposition. B1 mass mean/median were 14.8/10.4 mg/m²/day and visible-count mean/median were 2,359/2,041 particles/m²/day; B2 values were 14.7/6.5 mg/m²/day and 1,834/1,600 particles/m²/day, respectively (Table 5). Table 5 identifies B2 Hall C as highest for mean mass rate (24.4 mg/m²/day), B1 Hall D as highest for mean visible-count rate (2,514.1 particles/m²/day), and B2 Hall A as lowest for both means. Table 4 shows the highest mean mass rates at goalposts and lowest at plenums in both buildings. Table 5 provides the hall summaries and comparisons within each building.

Conclusions: Surface accumulation varied by location and particle-size population. The observed trends suggest that the large particles did not originate in the plenum, although their source was not confirmed. The coarse visible particles and fine microscopy objects represent distinct populations. These observations describe one week at the sampled positions; they do not establish airborne concentrations, particle composition, or a cleanliness classification for any hall.

INTRODUCTION

The client asked ARE Labs to measure how quickly airborne particles settle onto horizontal surfaces inside two data-center buildings, B1 and B2, and to describe the size and appearance of the settled material. Collection slides were exposed for one week at client-selected floor, goalpost and plenum positions in each of the four data halls of both buildings. ARE Labs then evaluated the returned slides by gravimetric analysis, visible particle counting, and microscopy with automated image analysis.

Deposition is reported on a common basis of collection-surface area and exposure time. Mass change per unit area per day is the primary measure and is presented first, followed by visible-particle count rates, the microscopy size profile, and representative images. Results are grouped by the building, hall and position descriptors recorded with each slide. Summary results are presented in this public copy.

STUDY DESIGN

The sampling plan covered buildings B1 and B2, each containing Data Halls A through D. Within each hall the client selected sampling positions in three categories: floor positions in the hot aisle (HA), goalpost positions (GP) approximately 10 ft above the floor and approximately 5 ft below the suspended ceiling, and plenum positions, for which the elevation was not recorded. Each slide was mounted horizontally with its collection surface facing upward, and its holder exposed the full slide face for the duration of the collection period.

ARE Labs prepared 135 slides for the study. Of these, 126 were deployed at the site and nine served as reference specimens that were never exposed. The shipping controls were prepared, weighed and packaged in the same way as the exposed slides, traveled to the site and back in the same shipments, and were not opened. The reference specimens were weighed and counted on the same schedule as the exposed slides. **Table 1** gives the distribution of exposed slides by building, hall and position, and the reference groups.

Building and data hall	Floor (HA)	Goalpost (GP)	Plenum	Total
B1 Data Hall A	4	7	4	15
B1 Data Hall B	3	8	4	15
B1 Data Hall C	4	8	4	16
B1 Data Hall D	4	8	4	16
B1 subtotal	15	31	16	62
B2 Data Hall A	4	8	4	16
B2 Data Hall B	4	8	4	16
B2 Data Hall C	4	8	4	16
B2 Data Hall D	4	8	4	16
B2 subtotal	16	32	16	64
Deployed total	31	63	32	126
Reference group				Total
Unopened shipping control				3
Blank				4
Unused				2
All specimens				135

Table 1: Test matrix. Number of collection slides deployed by building, data hall and position, and the reference specimens that accompanied the study. Three deployed slides were excluded from the primary comparison (see Samples Received).

SAMPLING LOCATIONS

A supplied floor plan oriented the sampling locations. The public copy omits the overview plan. Entrance, rear, center-side and outer-side descriptors identify the sampled groups. The drawing does not locate individual slides and was not used to derive distances.

Each slide identifier links the laboratory measurements to the building, hall, aisle and position recorded on the sampling manifest, and these descriptors are the basis for every grouping in this report. The spatial resolution of any comparison is therefore limited to the descriptors available for the slides in that group.

SAMPLES RECEIVED

The exposed slides and reference specimens were shipped to ARE Labs after collection and received under chain of custody. The package arrived with packaging and seals intact, and the enclosed holders were reconciled against the manifest on receipt. Two

slides, S05 and S06, arrived damaged and were withdrawn from the primary comparison. A third slide, S07, carried a visible residue band across its surface and was also withdrawn; the collection team reported occasional wet cleaning near that position, although the residue was not traced to a specific source. The remaining 123 exposed slides form the primary data set.

Slides were deployed for seven to eight days and collected after exposure. Recorded start and end times give each slide's exposure duration, as recorded in the source study records.

MAJOR EQUIPMENT USED

OPTICAL MICROSCOPY

Slides were examined by calibrated microscopy at two magnifications. Representative images were recorded for analysis (Figure 2), with the image scale set using a reference.

Figure 1: Facility plan omitted from the public copy.



Figure 2: Optical microscope used for slide imaging.

ANALYTICAL BALANCE

All slide weights were recorded on an analytical balance with 0.01 mg readability (Figure 3). Each slide was weighed twice before shipment and twice after return.



Figure 3: Analytical balance used for duplicate slide weighing.

SLIDE HOLDERS

Each slide traveled in a capped holder made in the ARE Labs shop. The holder protects the collection surface during shipment and handling and, with the cap removed, exposes the full slide face during collection. The shipping controls remained capped throughout.

Equipment or software	Study use
Optical microscope	Slide examination at two magnifications with calibrated imaging.
Calibrated stage micrometer	Image-scale reference imaged at the study settings.
Analytical balance	Duplicate weighing of every slide before and after exposure; readability 0.01 mg.
ARE Labs slide holders	Capped holders that protect the slide in transit and expose the full slide face during collection.
Image-analysis software	Automated object identification, counting and equivalent-circular-diameter measurement with one pipeline applied to all fields.

Table 2: Laboratory equipment and software used in the study.

IMAGE ANALYSIS

Calibrated microscope images were analyzed to identify, count, and measure objects. A consistent processing method was used for the reported size profile. Table 2 summarizes the equipment and software.

METHODS

SLIDE PREPARATION AND SHIPMENT

ARE Labs cleaned new 3 × 1 inch glass slides, labeled each with a unique identifier, and recorded two pre-exposure weights per slide. Each slide was then placed in its holder, capped, and packed for shipment to the site. The shipping controls were capped at ARE Labs and were not opened until they had returned to the laboratory.

DEPLOYMENT AND RETURN

The client deployed the slides at the selected positions, removed the caps to expose the collection surfaces, and recorded the start time for each slide. After the collection period the caps were replaced, the end times were recorded, and the holders were returned to ARE Labs under chain of custody. On receipt, every slide was weighed in duplicate before any other examination so that the gravimetric record was not affected by handling during counting or imaging.

GRAVIMETRIC MEASUREMENT

For each slide the two pre-exposure readings and the two post-exposure readings were averaged, and the signed mass change was calculated as the post-exposure mean minus the pre-exposure mean. Negative results were retained as measured. The mass-change rate was calculated by dividing the signed change by the nominal slide area and the recorded exposure duration in days. Because a small change in slide mass can arise from handling, moisture and balance variation

as well as from deposited material, the reference-specimen results are reported alongside the exposed-slide results.

VISIBLE PARTICLE COUNT

Each slide was examined over its entire surface by unaided visual inspection, and readily visible particles were counted. These particles fall in a nominal size category greater than 100 µm and are referred to in this report as coarse visible particles. The procedure yields a whole-slide count for this category; it does not measure the diameter of individual particles. The count rate was calculated by dividing the whole-slide count by the nominal slide area and the exposure duration in days.

MICROSCOPY AND IMAGE ANALYSIS

Slides were examined at two magnifications. Calibrated images were analyzed to identify objects and measure their projected area. Size is expressed as equivalent circular diameter (ECD), the diameter of a circle with the same projected area as the object.

The analyzed size window was 1.12 to 100 µm ECD. Image selection, segmentation, and overlapping objects can affect the reported profile, which describes the imaged material rather than every particle on a slide. The smallest size bin lies near the practical resolution of the imaging setup and should be interpreted accordingly. Within-slide size fractions were calculated for each slide and then averaged with equal weight across slides.

Reported quantity	Calculation basis
Signed mass change (mg)	Mean post-exposure weight minus mean pre-exposure weight.
Mass-change rate (mg/m ² /day)	Signed mass change divided by nominal slide area and exposure duration in days.
Visible count rate (particles/m ² /day)	Whole-slide visible count divided by nominal slide area and exposure duration in days.
Retained object count (per slide)	Objects retained by image analysis, 1.12–100 µm ECD.
Size profile (%)	Fraction of retained objects in each ECD bin, calculated within each slide and averaged with equal weight across slides.

Table 3: Calculation definitions. The nominal slide area of a 3 × 1 inch slide is 0.00193548 m² (1935.5 mm²).

CALCULATIONS AND DATA TREATMENT

All rates in this report are gross values. They include any material present on the slide from preparation, shipment and handling in addition to material deposited at the site, and no background subtraction has been applied. Reference specimens were never exposed, so their results are reported as mass change in milligrams and as counts per slide rather than as rates. **Table 3** defines each reported quantity.

The overall mean visible-count rate is the arithmetic mean of the 121 available primary-slide rates. Each slide rate equals its whole-slide visible count divided by 0.00193548 m² and its recorded exposure duration in days. The resulting mean, 2,089.9 particles/m²/day, rounds to 2,090. It is not an average of the hall means. The overall median is the 61st value after the 121 rates are sorted, approximately 1,774 particles/m²/day. For an even-sized group, the median is the average of its two middle values.

The ISO 14644 series was written for cleanrooms and controlled environments rather than operating data halls, so the procedure was adapted from its particle-deposition methods: ISO 14644-3 for the test method and ISO 14644-17 for the application of deposition rates. The sampled halls are not cleanrooms, and this study does not claim conformance to either standard; it follows their principles with adaptations for

the site and the client's positions. Summary statistics are reported with the number of slides they represent, and the spread among slides describes the observed variation rather than an acceptance limit.

RESULTS

MASS ACCUMULATION

Figure 4 and **Table 4** present the mass-change rates by building and position, with reference specimens listed for comparison. Across the primary slides, the mean rate was 14.7 mg/m²/day and the median was 7.5 mg/m²/day. Mean rates at the floor and goalpost positions were 17.6 and 18.3 mg/m²/day in B1, and 12.9 and 20.8 mg/m²/day in B2. The B2 goalpost group had the highest mean rate among the six position groups. Both plenum groups had the lowest mean rate within their buildings, 5.5 mg/m²/day.

Individual slides spread widely around each group mean, as the points in **Figure 4** show. Reference-group mean mass changes were 0.000 mg for blanks, +0.130 mg for unopened shipping controls and +0.298 mg for unused slides. These are changes per slide, not exposure-normalized rates. The summaries show lower mass accumulation at plenum positions than at floor and goalpost positions, without establishing the cause.

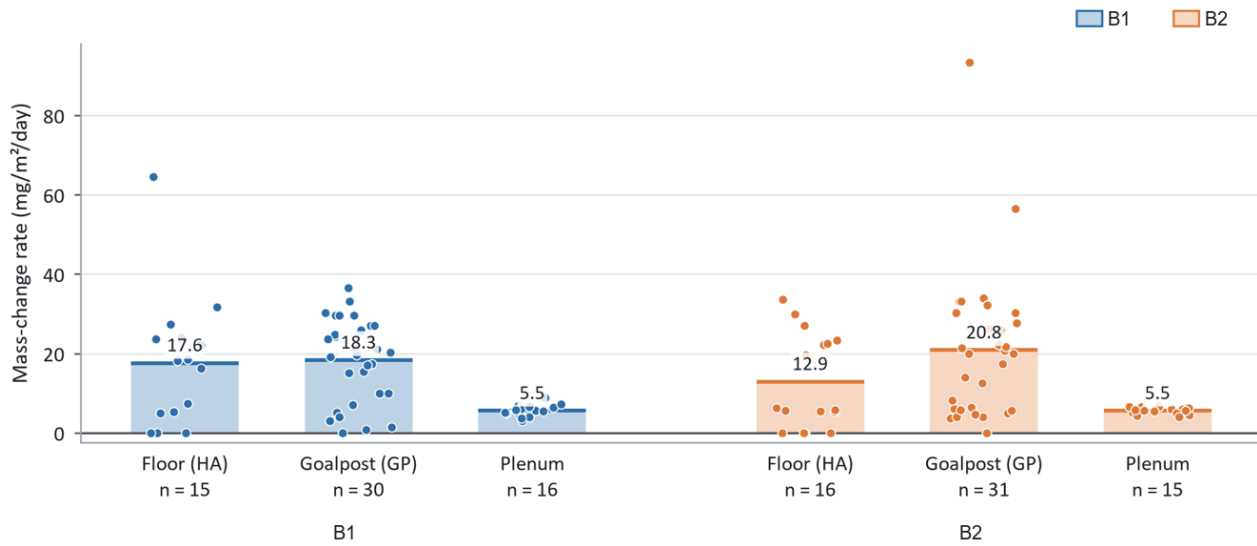


Figure 4: Mean signed mass-change rate by building and position for the 123 primary slides. Points are individual slides; the shaded band spans the range of mass change measured on the reference specimens, expressed on the same axis. Negative values are measured losses in slide mass, not negative deposition.

Building and position	n	Mean mass rate (mg/m ² /day)	Median mass rate (mg/m ² /day)	Mean count rate (particles/m ² /day)	Median count rate (particles/m ² /day)
B1 Floor (HA)	15/13	17.6	18.1	1936.1	1919.1
B1 Goalpost (GP)	30/30	18.3	19.9	2553.8	2066.7
B1 Plenum	16/16	5.5	5.5	2163.5	1882.1
B2 Floor (HA)	16/16	12.9	6.0	1822.2	1697.6
B2 Goalpost (GP)	31/31	20.8	19.9	2059.5	1919.1
B2 Plenum	15/15	5.5	5.5	1786.2	1623.8
All primary slides	123/121	14.7	7.5	2,090	1,774

Reference group	n	Mean mass change (mg)	Mean visible count per slide
Unopened shipping control	3	0.130	11.3
Blank	4	0.000	00.0
Unused	2	0.298	34.0

Table 4: Mass-change and visible-count rates by building and position for the primary slides, with the reference specimens. Reference specimens were not exposed and are reported as mass change and count per slide. In n (mass/count), the first number is the number of reported mass entries and the second is the number of recorded whole-slide visible counts. For B1 floor, 15/13 means 15 mass entries and 13 visible counts; S08 and S09 have microscopy results but no recorded whole-slide visible count.

LOCATION PATTERNS

Tables 4 and 5 summarize mass-change and count rates by building, position and hall. Mass and visible-count patterns differ: B2 Data Hall C had the highest mean mass rate (24.4 mg/m²/day), while B1 Data Hall D had the highest mean count rate (2,514.1 particles/m²/day). Table 4 shows higher mean count rates at

goalpost positions in both buildings. The lowest mean count rate was at the B1 floor and B2 plenum positions; plenum median count rates were lowest in both buildings.

The highest median visible-count rate was in B1 Data Hall A (2,288.1 particles/m²/day), followed by B1 Hall D (2,251.2) and B2 Hall D (2,066.7). The lowest was in B1 Hall C (1,439.3), followed by B2 Halls C (1,513.1) and A (1,550.0). The highest median was about 1.6 times the lowest.

Figure 5: Overview map omitted. Additional heat maps are retained in Appendix A.

Building and data hall	n	Mean mass rate (mg/m ² /day)	Median mass rate (mg/m ² /day)	Mean count rate (particles/m ² /day)	Median count rate (particles/m ² /day)
B1 Data Hall A	15/13	17.3	22.1	2231.3	2288.1
B1 Data Hall B	14/14	21.2	24.0	2462.1	1992.9
B1 Data Hall C	16/16	12.9	12.7	2043.6	1439.3
B1 Data Hall D	16/16	8.6	6.1	2514.1	2251.2
B2 Data Hall A	16/16	3.7	4.2	1637.7	1550.0
B2 Data Hall B	14/14	9.8	5.8	2045.6	1771.4
B2 Data Hall C	16/16	24.4	22.9	1817.6	1513.1
B2 Data Hall D	16/16	21.7	21.6	2242.0	2066.7

Table 5: Mass-change and visible-count rates by data hall for the primary slides. The n column gives mass entries/recorded visible counts, as defined in Table 4.

VISIBLE PARTICLE COUNTS

The primary visible-count results had a mean gross rate of 2,090 particles/m²/day and a median of 1,774 particles/m²/day. The reference specimens also carried visible particles (**Table 4**), so the reported rates include background material and have not been corrected by subtraction. B1 Data Hall D had the highest hall mean rate, while B1 Data Hall A had the highest median. Mean and median rankings therefore describe different aspects of the observed distribution.

PARTICLE SIZE PROFILE

Image analysis retained 12,501 objects across 123 primary slides. Microscopy at two magnifications covered a 1.12–100 µm ECD window.

Figure 6 shows the reported size profile. Half of the retained objects fell in the 1.12 to 1.5 µm plotted bin. The cumulative profile shows 76% below 2 µm, 93% below 3 µm, and 98% below 5 µm.

Panel (c) shows the separate coarse visible category by position group. Particles in the nominal >100 µm category were counted by hand across each whole slide but were not individually sized. This count and the microscopy image analysis sample different areas and use different size definitions; they should not be combined.

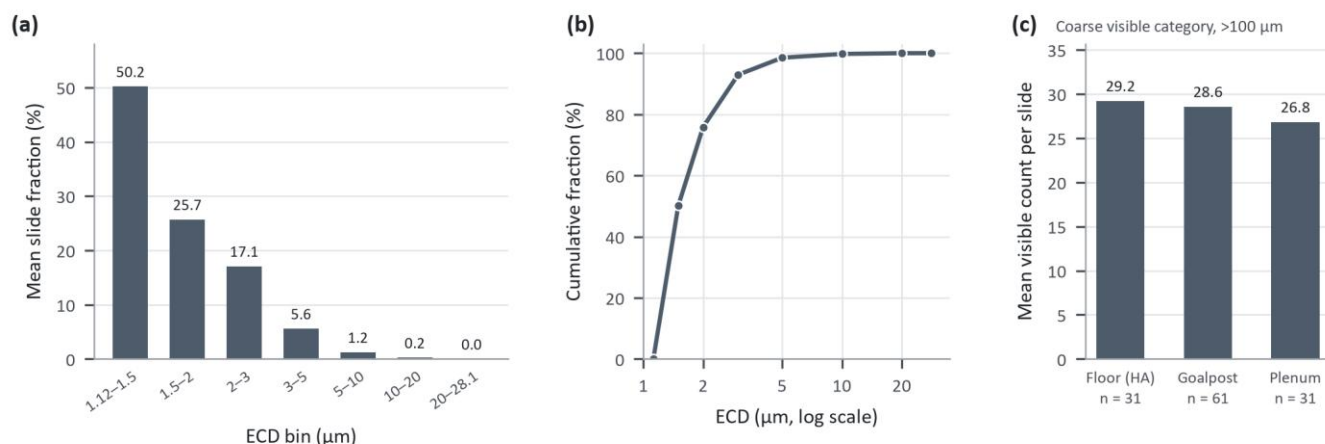


Figure 6: Reported size profile of objects retained by image analysis on the primary slides. (a) Mean within-slide fraction by plotted ECD bin. (b) Cumulative fraction on a logarithmic size axis. (c) Mean hand-counted coarse visible-particle count per slide (nominal >100 μm category) by position group; these particles were not individually sized.

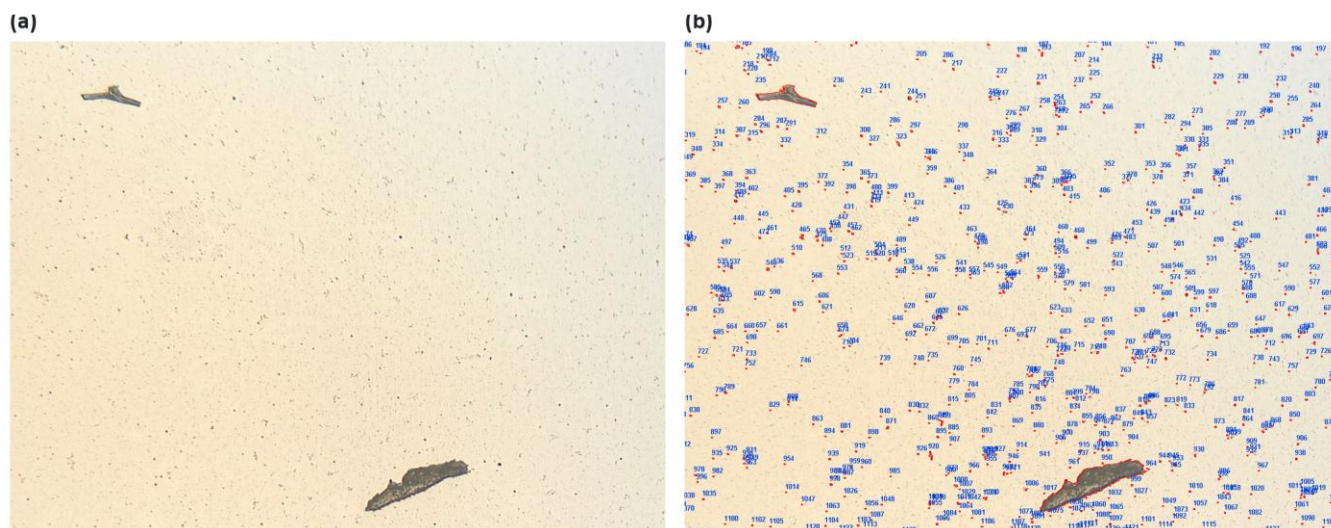


Figure 7: Representative microscope field (a) as captured and (b) with the object outlines identified by CellProfiler. Outlined objects are those counted in the size profile.

REPRESENTATIVE MICROSCOPY

Figure 7 pairs a representative field with the object outlines produced by CellProfiler for the same field. The fine material appears as discrete, near-circular objects distributed across the field, with occasionally larger irregular fragments that the pipeline outlines as single objects. The paired view shows which features the image analysis counts and which it does not and supports reading the size profile as a description of discrete fine particles rather than of films or smears.

DISCUSSION

ACCUMULATION PATTERNS

Mass accumulation and coarse-particle counts show different location patterns. Goalpost positions had the highest mean mass and visible-count rates within each building, while plenum positions had the lowest mean mass rates. B1 had higher mean visible-count rates than B2 at each corresponding position, but mass rates did not show a consistent building ranking. B2 Data Hall C had the highest hall mean mass rate; B1 Data Hall D had the highest hall

mean visible-count rate, and B1 Data Hall A the highest median visible-count rate.

Both plenum groups had positive mean mass rates of 5.5 mg/m²/day. Their higher mean microscopy counts and lower median coarse-particle rates are consistent with lower mass accumulation despite more fine particles. The count measures cover different size ranges and sampling areas; they do not quantify each population's contribution to mass.

COARSE PARTICLES AND POSSIBLE SOURCES

The coarse visible particles were distinct in size and appearance from the fine material seen by microscopy. Their size, in the hundreds of micrometers, is consistent with debris shed from nearby building materials, including overhead ceiling components, or released during maintenance activity, rather than with material carried long distances in the air stream. Fine particles below 5 µm, which dominate the microscopy profile, are consistent with material that stays airborne and settles slowly across the hall.

The observations do not establish the composition or the source of either population. The halls and positions with the highest rates, and Data Hall D of B1 in particular, are the natural starting points for a review of nearby materials, air-handling paths and maintenance activity during the collection period.

LIMITS OF INTERPRETATION

The location descriptors define general sampling groups. Plenum elevations and individual slide coordinates were not recorded, so these are group comparisons. Microscopy examined slides at two magnifications; its image-analysis count describes selected fields rather than whole slides. Visible particles were counted separately by hand across the whole slide without individual sizing. All rates are gross values that include material present before deployment.

The results describe surface accumulation at the sampled positions during one week. They do not convert to airborne particle concentrations, do not assign a cleanliness classification to any hall or building, and do not identify particle composition or an equipment-risk threshold.

TRENDS IN THE DATA

Two count measures were compared across the 123 primary slides: the whole-slide count of coarse visible particles (the nominal >100 µm category, by unaided visual inspection), the same measure as the visible-count rates reported above, and the retained object count of the image analysis divided by the number of imaged fields on the slide, referred to here as microscopy objects per image. The three slides excluded from the primary comparison (see Samples Received) are omitted from every statistic and figure in this section.

VISIBLE COUNTS BY BUILDING AND HALL

Hall means of the whole-slide visible count (**Figure 8**) ranged from 22.9 (Data Hall C) to 38.0 (Data Hall D) particles per slide in B1, and from 22.9 (Data Hall A) to 30.8 (Data Hall D) in B2; as visible-count rates, the eight hall means ranged from 1,637.7 to 2,514.1 particles/m²/day (Table 5). Data Hall D had the highest mean visible count in each building, and B1 Data Hall D was the highest of the eight halls, but the hall ranges overlapped substantially, so the Data Hall D lead is a modest tendency rather than a distinct separation between halls. Data Hall D slides ran from 24 to 64 particles per slide in B1 and 16 to 64 in B2; the other halls ran from 12 to 72 and 11 to 56. Data Hall D had the highest mean in three of the six building-by-position groups (B1 plenum; B2 goalpost and plenum) but at neither floor (HA) position.

MICROSCOPY COUNTS BY SAMPLING POSITION

Mean microscopy objects per image rose from floor to goalpost to plenum (**Figure 9**): 14.4 (n = 31), 17.3 (n = 61) and 18.8 (n = 31). The same ordering held within each building (B1 13.3, 16.1 and 17.1; B2 15.4, 18.4 and 20.6). It held in four of the eight halls and reversed in two; in the remaining two the goalpost mean was highest. Differences between position means, 1.5 to 4.4 objects per image, were small against within-position standard deviations of 8 to 10. Whole-slide visible counts showed no such rise, with position means of 29.2, 28.6 and 26.8 particles per slide, consistent with the position comparison in the Results.

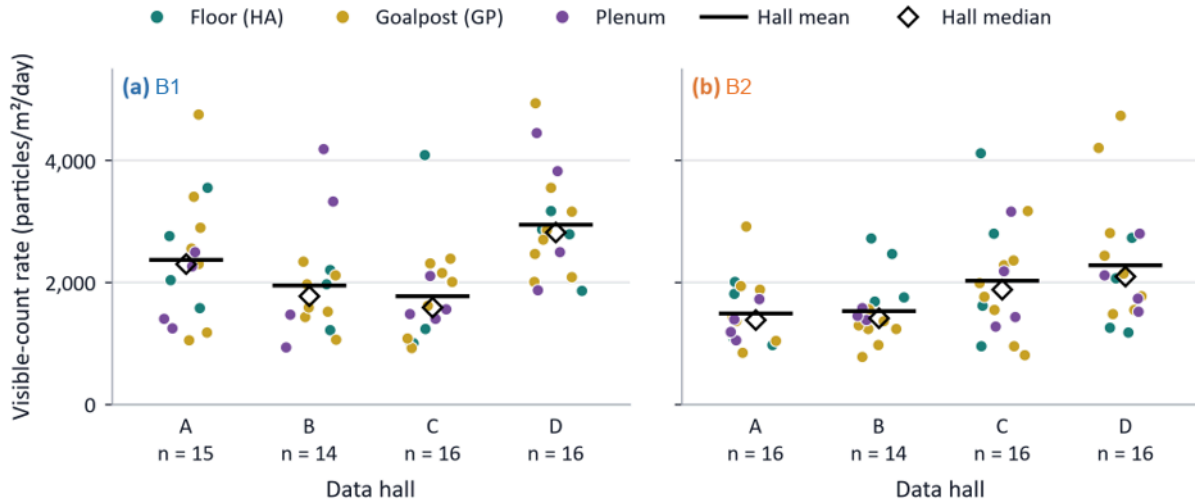


Figure 8: Whole-slide coarse visible-particle counts (>100 μm) by building and data hall for the 123 primary slides, as visible-count rates on the nominal slide area and each slide's recorded exposure duration (Table 3). Each point is one primary slide, colored by sampling position; bars mark hall means and diamonds hall medians. Hall groups mix sampling positions in unequal proportions.

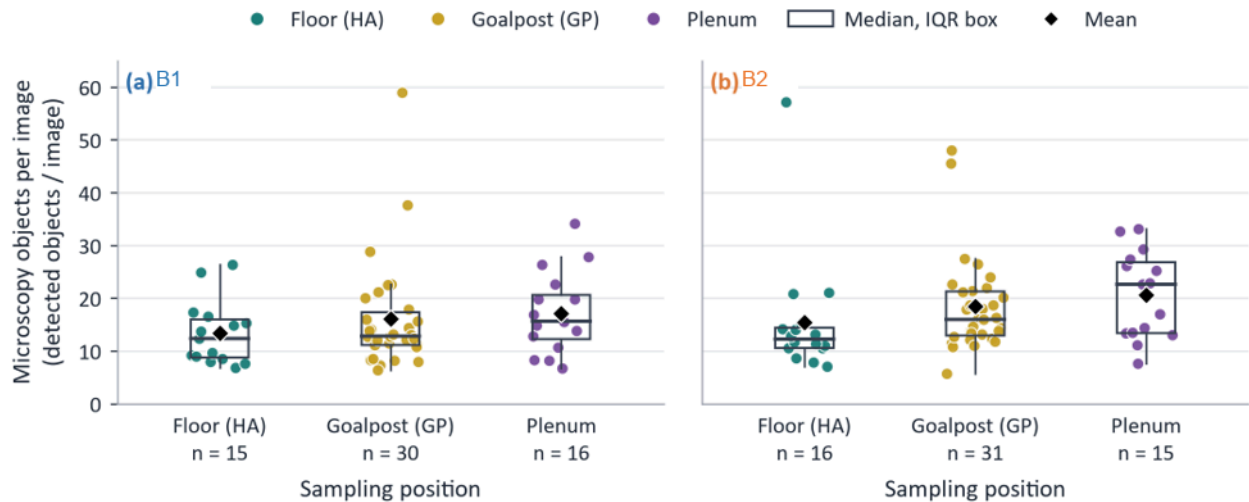


Figure 9: Microscopy objects per image by sampling position and building. Each point is one primary slide's average over its imaged fields; boxes show the median and interquartile range and diamonds the mean. Values are per image (one imaged field), not whole-slide totals, and the position groups are not a controlled test of height.

AGREEMENT BETWEEN THE TWO COUNT MEASURES

The whole-slide visible count, the same measure as the count rates reported above, placed B1 higher: 30.4 particles per slide ($n = 61$) against 26.2 for B2 ($n = 62$). The microscopy count ranked the buildings the other way, 18.2 objects per image in B2 against 15.7 in B1. The visible-count ordering held in three of the four halls; the microscopy ordering held in Data Halls A and C, while in Data Halls B and D the two buildings' means were within 0.2 objects per image of each other. Both building differences were smaller than the within-building standard deviations, and because the two measures cover different particle populations the reversal does not contradict the count results above.

Figure 10 plots the two measures for each slide. On both measures the highest values belonged to individual slides spread across several halls rather than to any one hall: the twelve highest visible counts came from six of the eight halls, four from B1 Data Hall D and three from B1 Data Hall A. S01 (B1 Data Hall A, goalpost) had the highest visible count, 72 particles per slide, about 4,750 particles/m²/day; S04 (B2 Data Hall D, goalpost) and S02 (B1 Data Hall D, goalpost) followed with 64 each. On the rate axis S02 sits highest because its exposure was the shortest of

the three. S02 also had the highest microscopy count, 59.0 objects per image against a pooled median of 14.0. S03 (B2 Data Hall A, floor) had 57.2 objects per image but 17 visible particles. Across the 123 slides, the Pearson correlation between the two measures was 0.24, falling to 0.15 when the four slides with the highest values on either measure were removed.

SCOPE OF THESE COMPARISONS

Group sizes were unequal: goalpost positions were sampled about twice as often as floor or plenum, and each hall group of 14 to 16 slides pooled the three positions unevenly. Height was not tested, for the reasons given under Limits of Interpretation. Microscopy objects per image are counts from fields examined at two magnifications. They describe the sampled fields, not the whole slide.

uncorrelated slide by slide (**Figure 10**), their building rankings need not agree. Count rates in this section use each slide's recorded exposure duration, as in Table 3. No significance testing was performed.

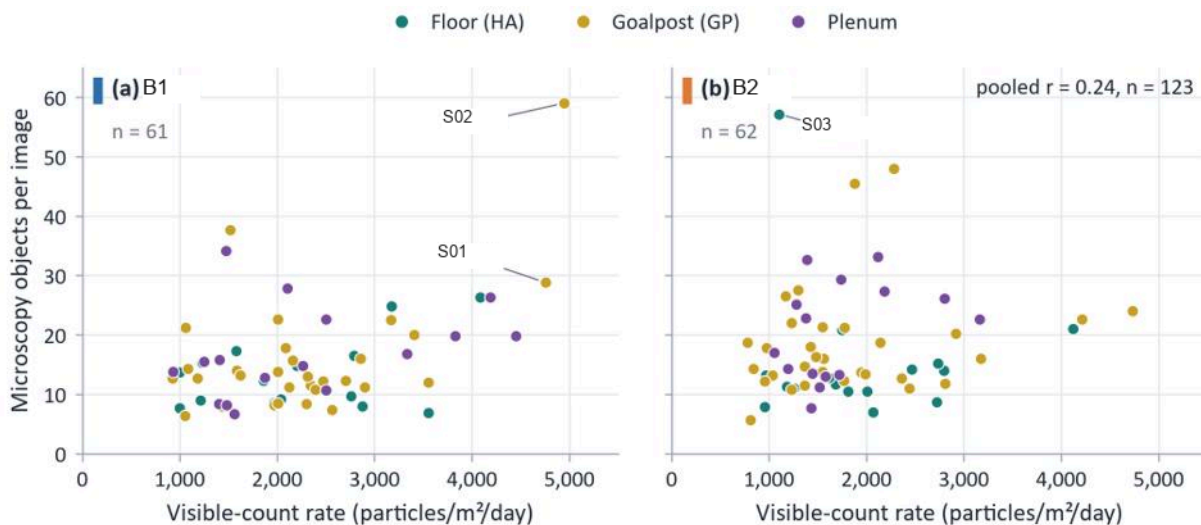


Figure 10: Whole-slide visible-count rate (nominal area, recorded exposure duration) against microscopy objects per image for the 123 primary slides, by building, with points colored by sampling position. The three slides discussed in the text, S01, S02 and S03, are labeled. The two measures describe different particle populations and sampled areas; the pooled Pearson r of 0.24 is descriptive only.

CONCLUSION

Surface particle accumulation was measurable at the sampled positions in B1 and B2 during the one-week collection period. The primary-slide mean mass rate was 14.7 mg/m²/day; the B2 goalpost group was highest at 20.8 mg/m²/day, and both plenum groups were lowest at 5.5

mg/m²/day. The mean coarse visible-particle rate was 2,090 particles/m²/day. B1 Data Hall D had the highest hall mean count rate (2,514.1 particles/m²/day), while B1 Data Hall A had the highest median (2,288.1 particles/m²/day).

The plenum's higher microscopy counts and lower median coarse-particle rates are consistent with its lower mass

accumulation. The trends observed in this study suggest that the large particles did not originate in the plenum, although their source was not directly established.

Two follow-up steps would sharpen these findings. Examining the coarse particles from the highest-rate slides by microscopy with elemental analysis would identify their composition and narrow the search for a source. A repeat deployment with the plenum elevations recorded and a larger set of shipping controls would allow position effects to be tested directly and the shipping background to be quantified.

REFERENCES

1. ISO 14644-3:2019, Cleanrooms and associated controlled environments – Part 3: Test methods. International Organization for Standardization, Geneva.
2. ISO 14644-17:2021, Cleanrooms and associated controlled environments – Part 17: Particle deposition rate applications. International Organization for Standardization, Geneva.
3. Stirling, D. R., Swain-Bowden, M. J., Lucas, A. M., Carpenter, A. E., Cimini, B. A., and Goodman, A. CellProfiler 4: improvements in speed, utility and usability. BMC Bioinformatics 22, 433 (2021).
4. Sampling layout, drawing supplied by the client for this study.

Public-copy note: B1 and B2 are anonymized building labels. S01-S11 are anonymized sample labels. Individual raw-data tables and non-map appendices have been removed. Appendix A retains the additional heat maps and their stated interpretation limits.

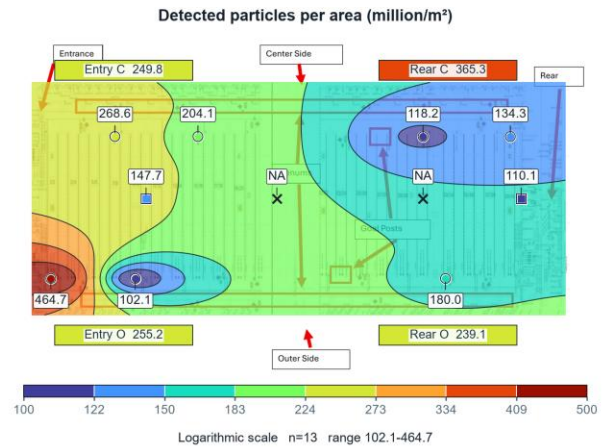
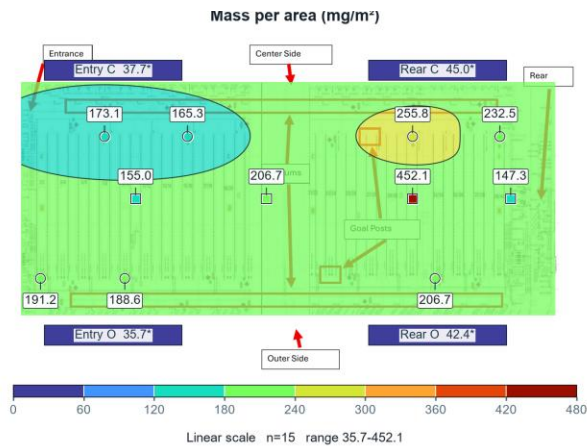
Disclosure: ARE Labs reported no financial affiliations or involvement with the commissioning client.

APPENDIX A – CONTOUR PLOTS OF THE SAMPLED LOCATIONS

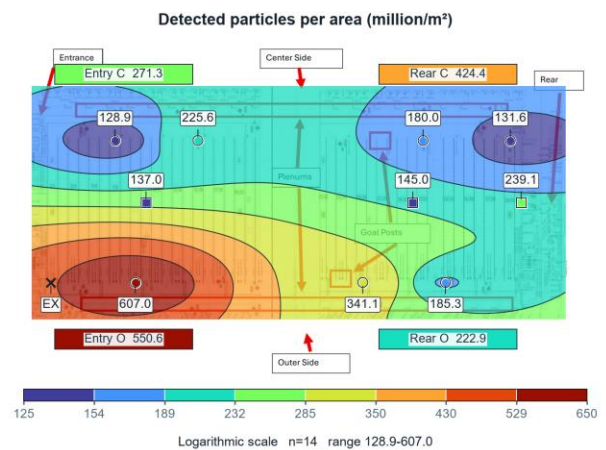
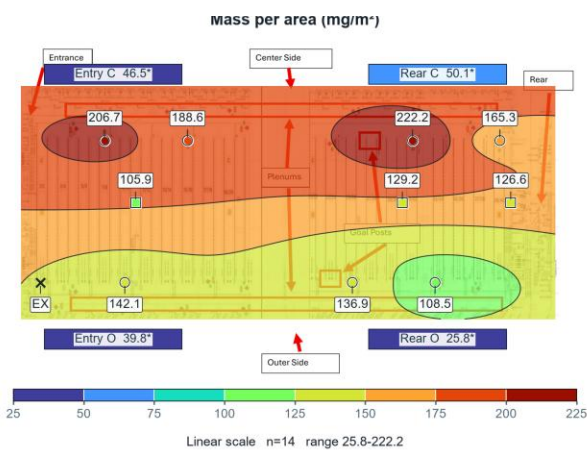
B1

Halls A through D. Hall-specific color scales preserve local variation; compare numerical values, not colors between halls.

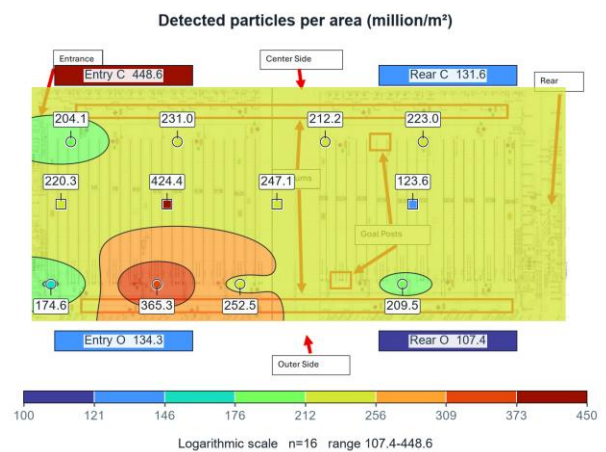
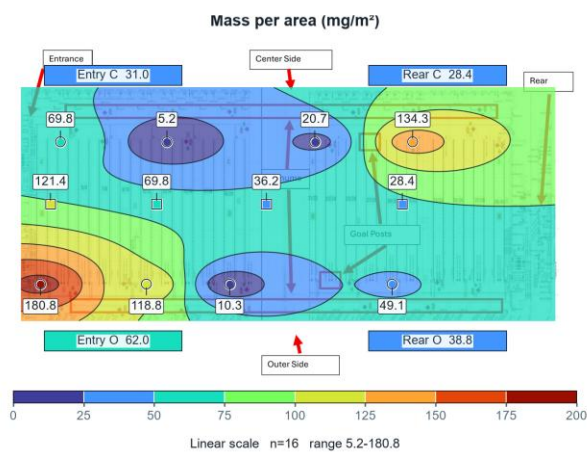
Hall A 15 included locations



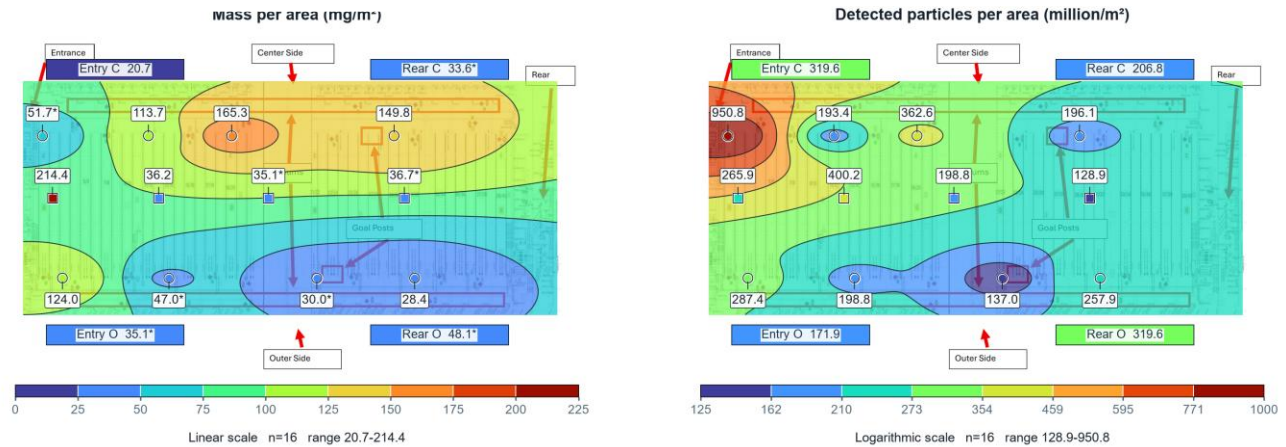
Hall B 14 included locations



Hall C 16 included locations



Hall D 16 included locations



Circles and contours: goal posts (~10 ft). Squares: floor. Tiles: plenum (elevation not recorded). NA: missing count. EX: excluded slide.

Contours interpolate goal-post readings only (IDW p=2), including extrapolation. Positions and plenum tiles are approximate; the same supplied plan represents

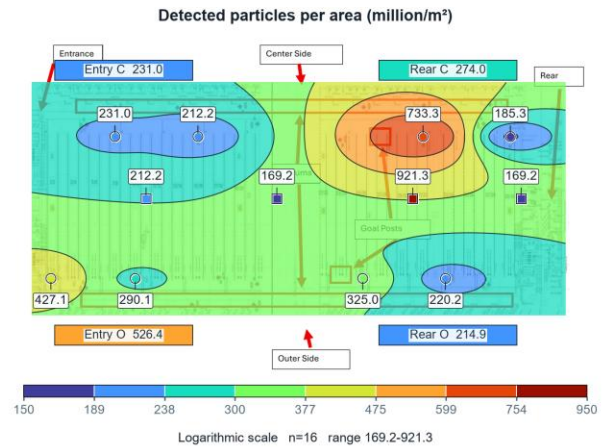
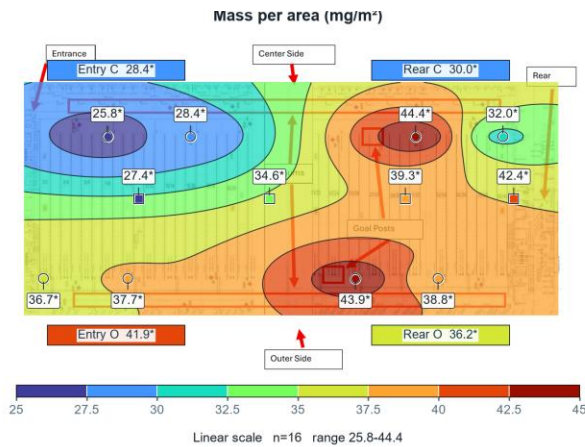
Mass = BJ / nominal slide area (0.00193548 m²). Particle density = Q / imaged area + AB (>100 µm) / slide area.
No background subtraction or time normalization. Imaged fields are assumed representative and nonoverlapping.

Source: study records and supplied layout. Logarithmic tick labels are rounded.

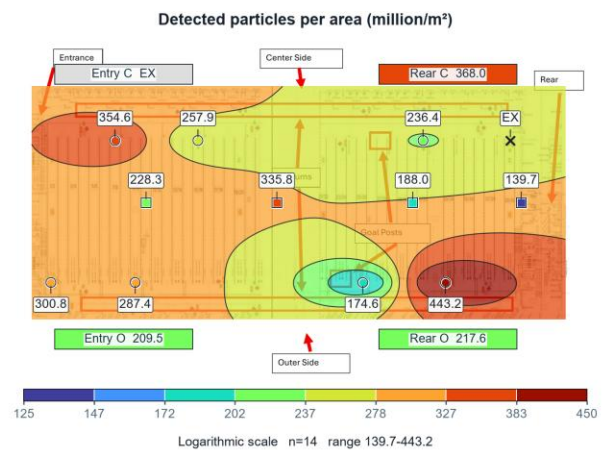
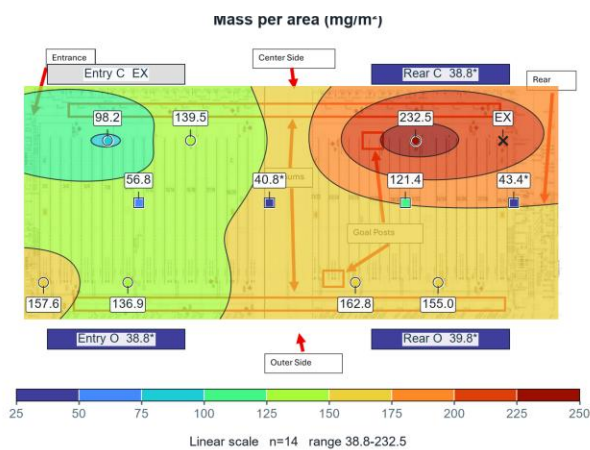
B2

Halls A through D. Hall-specific color scales preserve local variation; compare numerical values, not colors between halls.

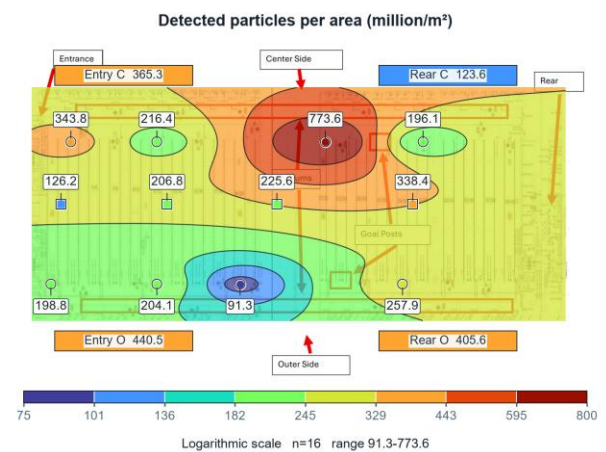
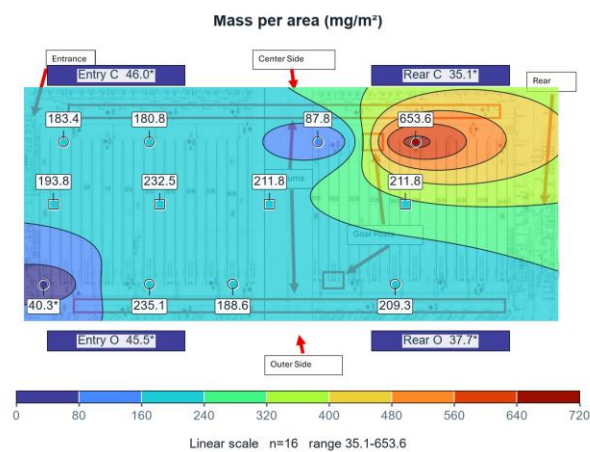
Hall A 16 included locations



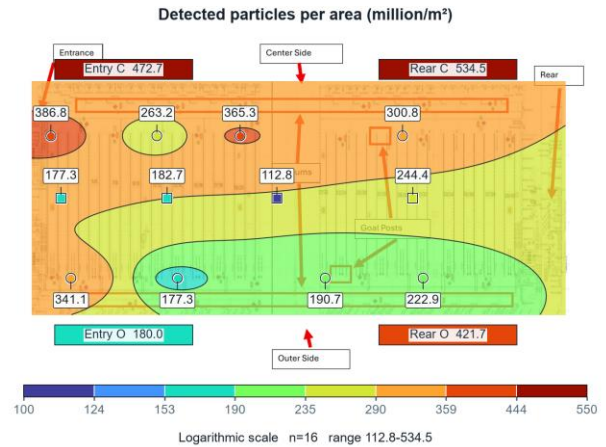
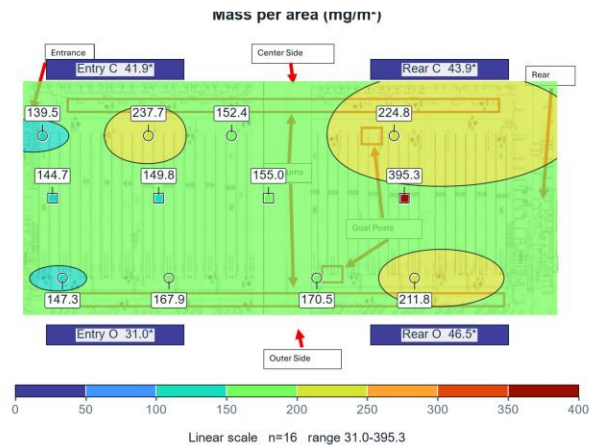
Hall B 14 included locations



Hall C 16 included locations



Hall D 16 included locations



Circles and contours: goal posts (~10 ft). Squares: floor. Tiles: plenum (elevation not recorded). NA: missing count. EX: excluded slide.

Contours interpolate goal-post readings only (IDW p=2), including extrapolation. Positions and plenum tiles are approximate; the same supplied plan represents

Mass = BJ / nominal slide area (0.00193548 m²). Particle density = Q / imaged area + AB (>100 µm) / slide area.
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