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January 18, 2019

Rachel S. Vroman
Fabrication Lab
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48 Quincy Street
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Ref: Indoor Air Quality Assessment during Fabrication Activities
Gund Hall, Harvard University Graduate School of Design, Cambridge, Massachusetts
TRC Project 322071

Dear Ms. Vroman:

Enclosed please find the report that summarizes indoor air quality (IAQ) monitoring performed by TRC Environmental (TRC) during various fabrication activities in Gund Hall at the Harvard University Graduate School of Design (Harvard), Cambridge, Massachusetts on December 5 – 7, 2018.

The monitoring was conducted as an initial assessment of IAQ related to potential emissions associated with 3D printing and other fabrication activities that take place in Gund Hall.

Should you have any questions or need additional information, please do not hesitate to contact us at 781.933.2555.

Sincerely,
TRC Environmental

Marley Carroll
Industrial Hygienist

Reviewed by:

Ann D. Eckmann

Ann D. Eckmann, CIH
Industrial Hygiene Group Leader

Enc.

INDOOR AIR QUALITY ASSESSMENT REPORT

HARVARD UNIVERSITY GRADUATE SCHOOL OF DESIGN
48 QUINCY STREET
CAMBRIDGE, MASSACHUSETTS

December 5 – 7, 2018

Prepared for:

Ms. Rachel S. Vroman
Fabrication Lab
Harvard University Graduate School of Design
48 Quincy Street
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Prepared by:

TRC Environmental
300 Wildwood Avenue
Woburn, Massachusetts

January 18, 2019

TRC Project 322071

Contents

1.0 INTRODUCTION

At the request of the Harvard University Graduate School of Design (Harvard), TRC Environmental (TRC) conducted indoor air quality (IAQ) monitoring for selected air constituents during several fabrication operations in Gund Hall, 48 Quincy Street, Cambridge, Massachusetts.

The assessment was conducted during the period from December 5 through December 7, 2018, which was a period of significant fabrication activity in Gund Hall and was conducted as an initial assessment of IAQ related to potential emissions associated with 3D printing and other fabrication activities that take place in Gund Hall.

The IAQ monitoring sought to characterize these emissions both to evaluate potential exposure of students and staff to various airborne constituents, and to provide identification of constituents that are transported through local exhaust systems to the outdoors.

The IAQ monitoring targeted the following areas: the multi-level student group work areas; the 3D printer bank locations near the 4-south restrooms; the L40 area where laser cutting and 3D printing is conducted; and the L32-L35 wood shop. A reference location (L02) was also monitored, which is an office location.

The following constituents were monitored in one or more locations:

- Ultrafine Particles (UFP)
- $PM_{2.5}$ Particulate Matter
- PM_{10} Particulate Matter
- Total Volatile Organic Compounds (VOCs)
- Air sampling for total and specific VOCs
- Air sampling for a range of aldehydes

Background information for selecting the constituents to be monitored, results and comparison with application guidelines, and a summary of the findings and recommendations are presented in the following sections. Summary statistics of measurements, a description of the sampling and analytical methods used, the laboratory analytical reports, reference sources and detailed descriptions of VOC sample locations are included as appendices.

2.0 BACKGROUND AND OBSERVATIONS

2.1 Background Information

The following types of air sampling methods were used to conduct the assessment:

Continuous Two-hour Direct-reading Measurements. Hand-held instruments were placed in consecutive locations and recorded real-time airborne particulate (as $PM_{2.5}$ and PM_{10}), ultrafine particles and total VOC concentrations for a period of approximately two hours in each test location. This provides both the average concentration over the test period and records momentary variations in airborne concentrations of each monitored constituent.

Integrated Air Samples. Air samples were collected over approximate 6.75-hour or 48-hour periods and submitted to an analytical laboratory for determination of aldehydes and VOCs. This provides the average concentration of specific aldehydes and VOCs over the sampling period.

The rationale for selecting the monitored constituents is as follows:

Constituent	Description/Rationale for Selection
Ultrafine Particles (UFP)	Particle size range: 0.02 – 1 micron (µm) aerodynamic diameter. Associated with 3D printer and laser cutting emissions, and other small particle generation. These are of concern due to their potential to enter the deep lung region and penetrate tissue.
$PM_{2.5}$ Particulate Matter	50% of particle sizes less than or equal to 2.5 µm aerodynamic diameter. Potential wood shop and materials handling emissions, and an indoor air quality indicator. Potential to enter the deep lung region.
PM_{10} Particulate Matter	50% of particle sizes less than or equal to 10 µm aerodynamic diameter, potential wood shop, materials handling emissions, and an indoor air quality indicator. Potential to enter deep lung region and/or upper airways.
Total Volatile Organic Compounds (VOCs)	Organic compounds, associated with adhesives and spray coatings, also potential 3D printer and laser cutting emissions, without identifying specific VOCs that may be present.
Air sampling for total and specific VOCs	Collection and analysis of air samples to identify specific and total VOCs. For example, specific VOCs include styrene, which has been associated with printing ABS filament, and methyl methacrylate, which has been associated with printing PLA filament.
Air sampling for a range of aldehydes	Sampling and analysis of one air sample for a range of aldehydes, which are potential thermal decomposition products of materials during laser cutting.

Monitoring for the following constituents was conducted in the test locations as follows:

Location	Ultrafine Particulate	$PM_{2.5}$ Particulate Matter	PM_{10} Particulate Matter	TVOCs	Specific VOCs	Aldehydes Scan
Multi-level student group work areas: 1) 2nd floor near spray booth, and 2) 3rd floor center area	X	X	X	X	X	
Printer bank near 4-south restrooms	X	X	X	X	X	
L40 and/or associated rooms	X	X	X	X	X	X
Wood shop (L30 – 35)		X	X			
Reference location (L02)	X	X	X	X	X	

The main areas of concern for this project were the two multi-level student group work area locations, the printer bank near the 4-south restrooms and L40 (and/or associated L40C and L40D). The wood shop areas (L32 to L35) were sampled depending on the availability of equipment. As noted previously, direct-reading measurements were taken in the reference location (L02) throughout the period that direct-reading instruments were used.

2.2 Observations

All observed fabrication areas were active throughout the time that TRC was on site. The following conditions were noted:

- Spray paint, spray adhesive, glues in the multi-level student group work areas – some, but limited usage at desks outside of the designated spray area while TRC was on site.
- PLA was the 3D printing filament that TRC observed to be in use during the test periods.
- No other observations of note were recorded, except that 3D printers and laser cutting devices were used throughout the test period while TRC was on site.
- Hot wire cutting operations take place in a ventilated area on the 3rd floor of the multi-level student group work area; however, this activity was not thought to generate significant emissions compared with the spray booth and 3D printing activities and was not targeted for investigation during this initial assessment.
- Fabrication activities took place in all test locations during the assessment

3.0 RESULTS

3.1 Direct-reading Measurements of UFP, $PM_{2.5}$, PM_{10} and TVOCs

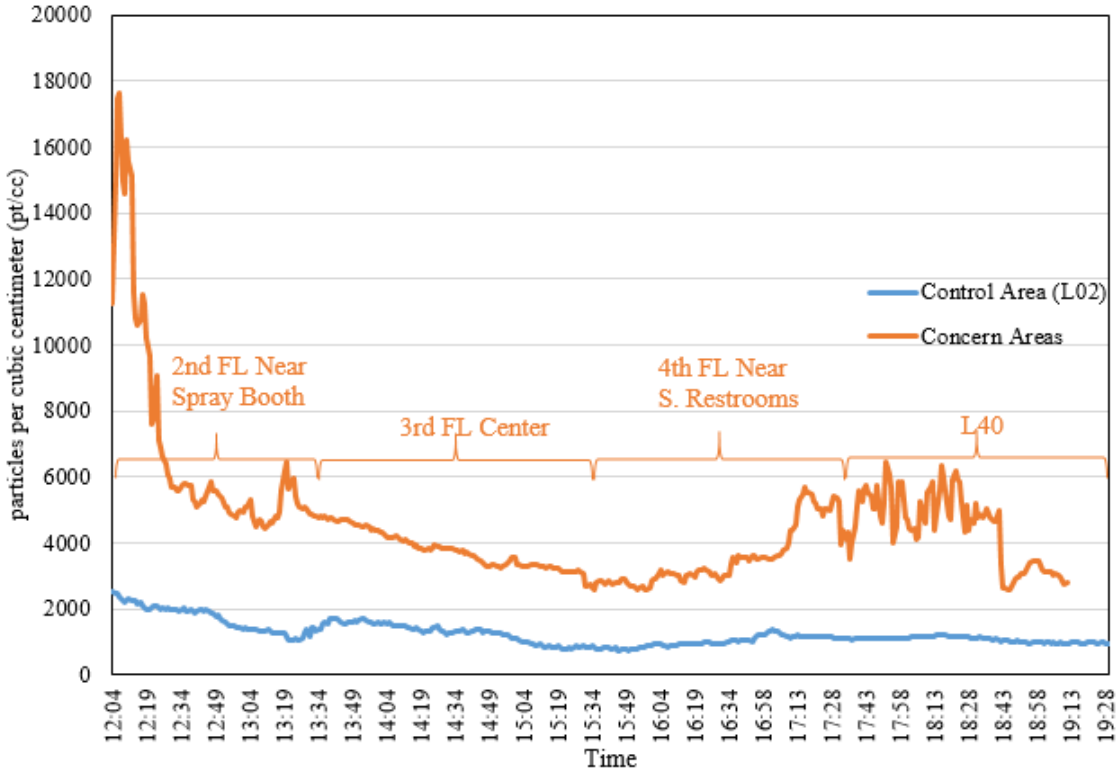
The direct-reading measurements were taken in a reference location (L02) and simultaneously in other test locations of concern. One set of instruments always remained in the reference location, while other instruments were either placed in one location or were moved to consecutive locations of concern for at least two hours per test location. On the 2nd, 3rd and 4th floors, direct-reading instruments were placed within approximately 10 feet of the VOC sample locations described in Appendix F. Otherwise, instruments were placed in a general location within the room number indicated.

The direct-reading measurement results are summarized graphically in the charts below.

3.1.1 UFP

The UFP measurement results are presented in Figure 1 below in concentration units of particles per cubic centimeter of air (particles/cc). The graphs below show brackets which depict the consecutive test locations over time.

Figure 1. Harvard University Graduate School of Design
Ultrafine Particles 0.02µm - 1µm
December 6, 2018



The UFP measured in all concern areas were in higher concentration compared to the control area. In addition to 3D printing emitting UFP, spray application of paints, adhesives and coatings also have the potential to introduce airborne UFP, and UFP concentrations were greatest at the 2nd floor near the spray booth test location.

Exposure Guidelines

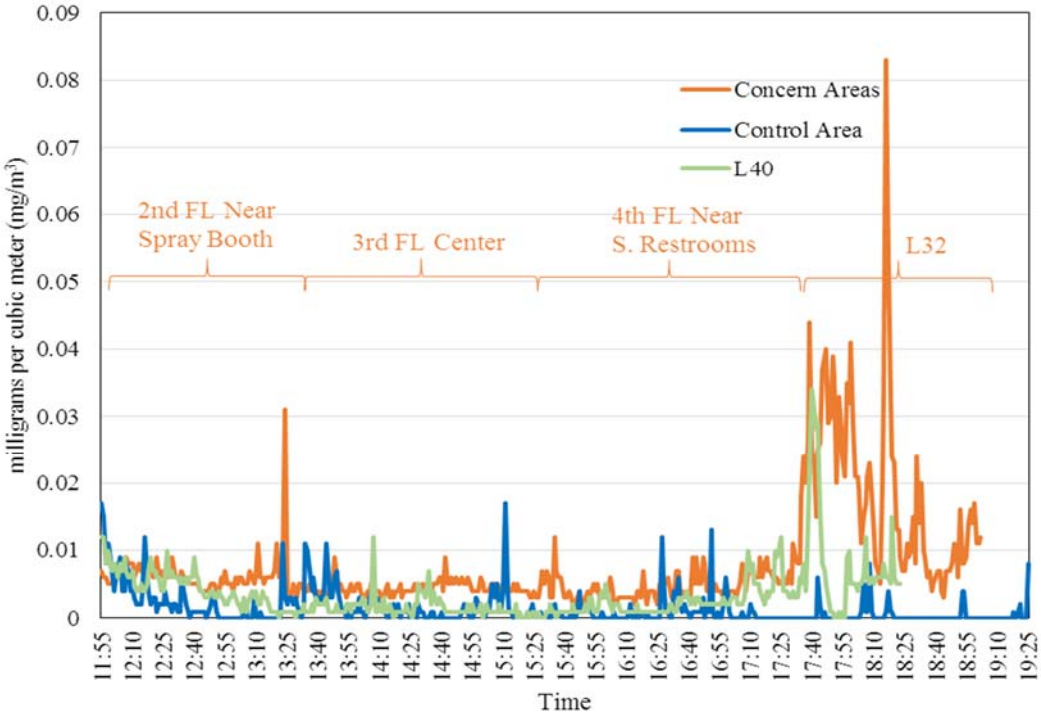
There are currently no exposure limits or guidelines for the types of UFP that is generated by PLA. The majority of studies of UFP emitted by desktop filament 3D printers that were reviewed by TRC have been conducted within test chambers. Some research suggests that UFP emissions are lower using PLA filament than ABS filament. One of the studies reviewed by TRC, regarding usage of an area that contained both desktop and industrial 3D printers, had UFP emissions up to 200,000 particles/cc. All of the measurements in Gund Hall were below this value.

3.1.2 $PM_{2.5}$

The $PM_{2.5}$ measurement results are presented in Figure 2 below in concentration units of milligrams per cubic meter of air (mg/m^3).

Measurements were taken using three instruments, including one that was moved throughout the three of the main areas of concern and L32, one that was placed in L40 for approximately 7 hours and one in the reference location (L02). The graphs below show brackets which depict the consecutive test locations over time.

Figure 2. Harvard University Graduate School of Design
Particulate Matter 2.5µm
December 6, 2018



The $PM_{2.5}$ measurement results are summarized below:

- $PM_{2.5}$ concentrations in the multi-level student group work areas, including 1) near the 2nd floor near the spray booth, 2) in the 3rd floor center location, and 3) at the 3D printer bank near the 4th floor south restrooms were all relatively low – the maximum $PM_{2.5}$ concentration was 0.031 mg/m^3.

- Similar $PM_{2.5}$ concentrations were measured in L40 with maximum concentrations of 0.034 mg/m^3.

- Room L32, which is part of the wood shop, measured relatively higher concentrations of $PM_{2.5}$ compared to other concern areas and the control area with a maximum concentration of 0.083 mg/m^3.

- The control area (room L02) had a maximum $PM_{2.5}$ concentration of 0.025 mg/m^3.

Exposure Guidelines

U.S. Environmental Protection Agency (EPA) National Ambient Air Quality Standard (NAAQS). The U.S. EPA has established a National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ in outdoor air of 0.035 mg/m^3 as a 24-hour average concentration. This value is used in this report as a guideline for evaluating indoor air quality.

The only concentration above 0.035 mg/m^3 was in the wood shop, where airborne particulate is anticipated due to activities there.

These concentrations are not considered to be unusual considering the fabrication activities taking place at the time of the measurements.

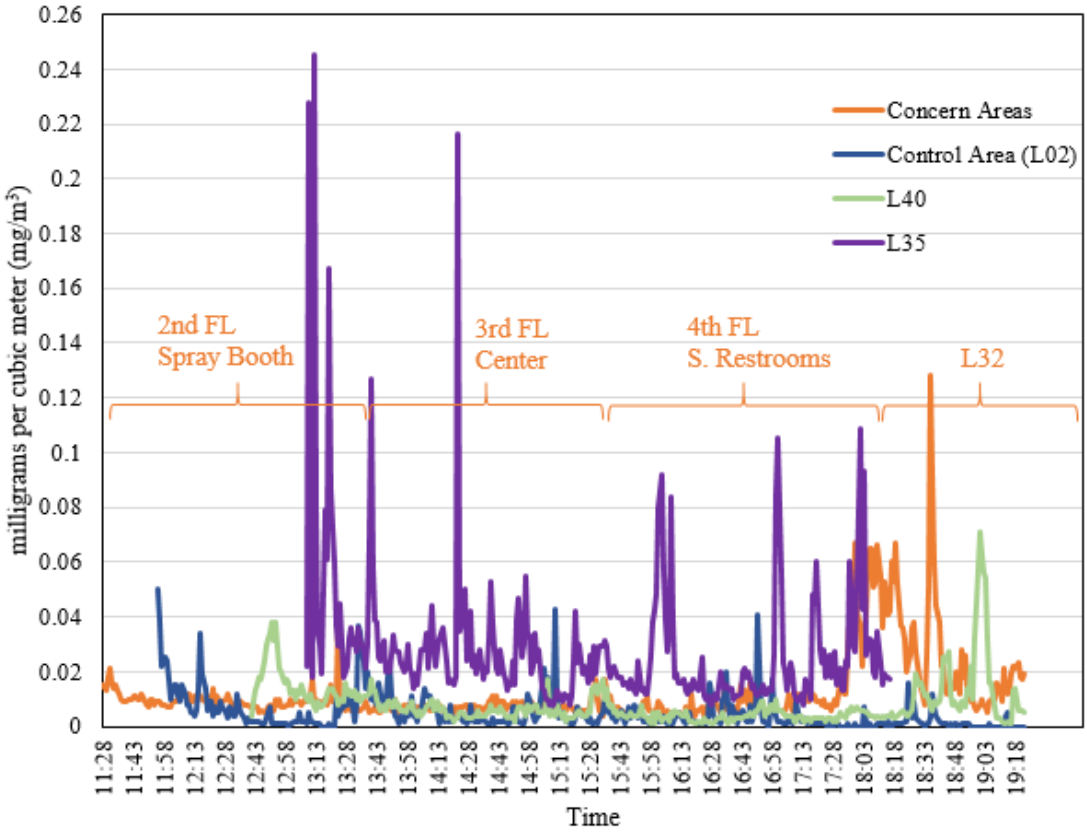
These size ranges are greater than the particle size anticipated for 3D printer emissions and would be expected to be greater in the wood shop, in comparison with the multi-level student work areas.

3.1.3 PM_{10}

The PM_{10} measurement results are presented in Figure 3 below in mg/m^3 concentration units.

Measurements were taken using four instruments, including one that was moved throughout the three of the main areas of concern, one that was placed in L35 (part of the wood shop) for approximately 5 hours, one that was placed in L40 for approximately 6 hours and the reference location (L02). The graphs below show brackets which depict the consecutive test locations over time.

Figure 3. Harvard University Graduate School of Design
Particulate Matter 10µm
December 6, 2018



The measurements of PM_{10} (particles with mean aerodynamic diameters of 10 microns) are summarized below:

- PM_{10} concentrations in the multi-level student group work areas, including 1) near the 2nd floor near the spray booth, 2) in the 3rd floor center location, and 3) at the 3D printer bank near the 4th floor south restrooms were all relatively low – the maximum PM_{10} concentration was 0.040 mg/m^3 near the spray booth.

- In L40 and L40C, the maximum PM_{10} concentrations were 0.071 mg/m^3 and 0.026 mg/m^3, respectively.

- In Room L32 and Rooms L33 - L35, which are part of the wood shop, PM_{10} concentrations were relatively higher, with maximum concentrations of 0.128 mg/m^3 in L32 and 0.245 mg/m^3 in L33-35.

- The maximum PM_{10} concentration in the control area (room L02) was 0.043 mg/m^3.

Exposure Guidelines

U.S. EPA NAAQS: The U.S. EPA NAAQS for PM_{10} in outdoor air is 0.150 mg/m^3 as a 24-hour average concentration.

Similarly to the $PM_{2.5}$ measurements, the PM_{10} measurements are not considered to be unusual in view of the fabrication activities taking place at the time of the measurements.

The only concentration above 0.150 mg/m^3 was in the wood shop, where airborne particulate is anticipated due to activities there.

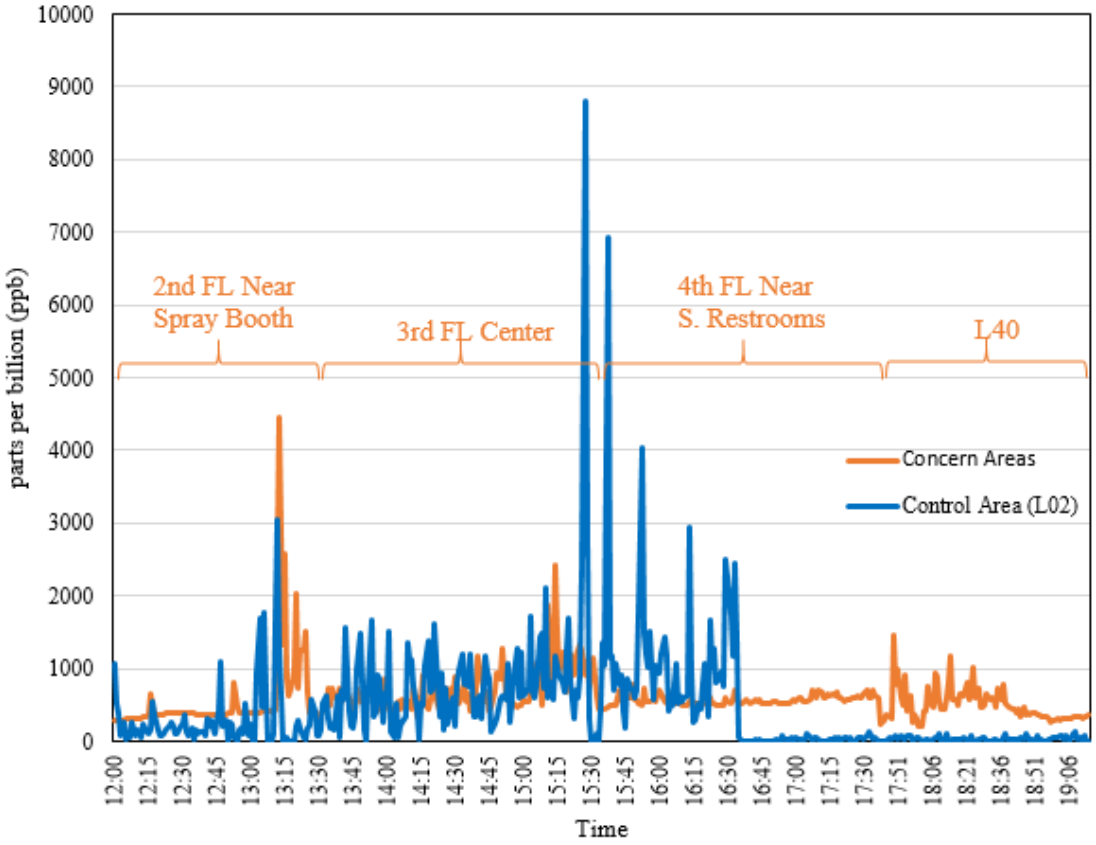
U.S. Occupational Safety and Health Administration (OSHA) and American Conference of Governmental Industrial Hygienists (ACGIH) occupational exposure limits:

Occupational exposure limits or guidelines have been established for workplace exposure to total particulate (closest in size distribution to PM_{10}) not otherwise regulated or specified. These are on the order of 10 mg/m^3 to 15 mg/m^3 as 8-hour average concentrations. For wood dusts, occupational exposure limits of 1 mg/m^3 (8-hour average) have been established for several types of wood and 0.5 mg/m^3 (8-hour average) for red cedar. None of the measurements in the wood shop areas were above these values.

3.1.4 TVOCs

The results of the direct-reading TVOC measurements are presented in Figure 4 below in concentrations units of parts per billion parts of air, by volume (ppb). The graphs below show brackets which depict the consecutive test locations over time.

Figure 4. Harvard University Graduate School of Design
Total Volatile Organic Compounds
December 6, 2018



The TVOC measurement results are summarized below:

- Of the concern areas, peak TVOC concentrations were greatest in the multi-level student work area locations, ranging from 263 to 4,467 ppb on the 2nd floor near the spray booth and from 331 to 2,423 ppb at the 3rd floor center location.

- TVOC concentrations in the 4th floor near the south restrooms were consistently closer to the average TVOC concentration in that location of 571 ppb.

- In L40, the TVOC concentrations ranged from a low of 210 ppb to a peak of 1,470 ppb, and in L40C the TVOC measurements never exceeded a maximum concentration of 391 ppb.

- The highest peak TVOC concentration occurred in the control area (L02), where concentrations ranged from a minimum of non-detect (< 20 ppb) to 8,791 ppb. The highest TVOC concentrations in this location occurred during the following time periods:

1:28 pm to 1:38 pm
2:05 pm to 2:45 pm
3:00 pm to 5:00 pm.

TRC did not note any specific activity that correlated with the peak concentrations in this location, which occurred between 3:00 and 4:00 pm on December 6, 2018.

Exposure Guidelines

There are no exposure guidelines for TVOCs that are directly applicable to the fabrication activities in Gund Hall.

The results of monitoring TVOCs are best evaluated by comparing results in each location with the air sampling results described under 3.2.1. In comparison with the long-term VOC sampling results, the measurements suggest wide variations in TVOC concentrations in the multi-level group work areas, in L40 and in the control location.

There are multiple sources of TVOCs during fabrication, including: those contained in spray and hand-applied coatings and adhesives; potential thermal decomposition products associated with 3D printing and laser cutting; and art/office supplies such as markers. Other sources of TVOCs include, but are not limited to, personal care products such as hand sanitizers, and cleaning products.

With the highest TVOC concentrations observed in the control location (L02), it appears that multiple sources of TVOCs make it difficult to isolate the impact of 3D printing and/or laser cutting operations on the observed TVOC concentrations.

3.1.5 Summary Statistics Table

A table of summary statistics of all of the direct-reading instrument results is included as Appendix A, and provides a good numeric comparison of results for each test location.

3.2 Results of Integrated Air Sampling for VOCs and Aldehydes

3.2.1 Results of Integrated Air Sampling for VOCs

The results of integrated air sampling for VOCs are summarized in Table 1 below in both ppb (concentration by volume) and mg/m^3 (concentration by mass) units:

Table 1. Volatile Organic Compound Sampling Results
Harvard University Graduate School of Design, 48 Quincy St., Cambridge, Massachusetts
December 5-7, 2018

Constituent	Concentration of Constituent in Air (mg/m^3/ppb)				
	2nd FL Near Spray Booth	**3rd FL Center**	**4th FL Near S. Restrooms**	**L40C**	**L40D**
Acetone	**0.260 / 110 ppb**	**0.150 / 65 ppb**	**0.140 / 58 ppb**	ND (<0.041) / (< 17 ppb)	**0.053 / 22 ppb**
n-Butyl Acetate	**0.061 / 13 ppb**	ND (<0.059) / (< 12 ppb)	ND (<0.059) / (< 12 ppb)	ND (<0.059) / (< 12 ppb)	ND (<0.059) / (< 12 ppb)
Methyl Ethyl Ketone (MEK)	ND (<0.045) (< 15 ppb)	ND (<0.046) (< 15 ppb)	ND (<0.045) (< 15 ppb)	ND (<0.046) / (< 15 ppb)	ND (<0.046) / (< 16 ppb)
Methyl Methacrylate	ND (<0.31) (< 76 ppb)	ND (<0.31) (< 77 ppb)	ND (<0.31) (< 76 ppb)	ND (<0.32) / (< 77 ppb)	ND (<0.32) / (< 77 ppb)
Styrene	ND (<0.068) / (< 16 ppb)	ND (<0.068) / (< 16 ppb)	ND (<0.068) / (< 16 ppb)	ND (<0.068) / (< 16 ppb)	ND (<0.068) / (< 16 ppb)
Pentane	ND (<0.038) / (< 13 ppb)	ND (<0.038) / (< 13 ppb)	**0.044 / 15 ppb**	**0.120 / 40 ppb**	**0.069 / 23 ppb**
Unidentified VOCs as n-hexane	**0.639 / 147 ppb**	**0.490 / 115 ppb**	**0.606 / 147 ppb**	**.0.120 / 27**	**0.148 / 32**
Total VOC as n-hexane	**0.960 / 270 ppb**	**0.640 / 180 ppb**	**0.790 / 220 ppb**	**0.240 / 67 ppb**	**0.270 / 77 ppb**

NOTES:
ND is non-detect.

The field blank data is included with the laboratory analytical reports in Appendix C-1. **All constituents in the field blank were non-detect.**

The list of all compounds included in the VOC compound search is included as Appendix C-2.

Methyl ethyl ketone was not detected on any of these samples in excess of minimum reporting limits. Methyl ethyl ketone was detected during analysis of aldehydes (see Table 2 below) so the minimum reporting limits for analysis of the VOC samples are shown here for comparison.

Detailed descriptions of the sample locations are shown in Appendix F.

TRC specifically requested that the laboratory report include methyl methacrylate and styrene, since these VOCs have been associated with printing PLA and ABS filaments, respectively. Neither methyl methacrylate nor styrene were detected on any of the samples in excess of the minimum reporting limits shown above.

Exposure Guidelines and Discussion

The analysis indicated that three VOCs, including acetone, n-butyl acetate and pentane were identified on one or more of the samples above minimum reporting limits. Of the VOCs identified above minimum reporting limits in Table 1, in addition to methyl methacrylate and styrene, the following exposure guidelines have been published:

Agency for Toxic Substances & Disease Registry (ASTDR) Minimal Risk Levels (MRLs). An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. Of the three identified VOCs or compounds of interest, MRLs were published only for **acetone** and **styrene** as follows:

Type of MRL	**Acetone**	**Styrene**
Acute exposure (1 to 14 days)	26 ppm (26,000 ppb)	5 ppm (5,000 ppb)
Intermediate exposure (15 to 364 days)	13 ppm (13,000 ppb)	no value established
Chronic exposure (1 year or longer)	13 ppm (13,000 ppb)	0.2 ppm (200 ppb)

US Environmental Protection Agency (EPA) reference concentration (RfC). The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure of a chemical to the human population through inhalation (including sensitive subpopulations), that is likely to be without risk of deleterious noncancerous effects during a lifetime. Of the three identified VOCs plus methyl methacrylate and styrene, RfCs were published only for **methyl methacrylate** and **styrene** of 0.7 mg/m^3 and 1 mg/m^3, respectively.

U.S. Occupational Safety and Health Administration (OSHA) and American Conference of Governmental Industrial Hygienists (ACGIH) occupational exposure limits:

Constituent	**OSHA**	**ACGIH**
Acetone	2,400 mg/m^3 (8-hr average)	594 mg/m^3 (8-hr average) 1,187 mg/m^3 (15 minute average)
n-Butyl Acetate	710 mg/m^3 (8-hr average)	238 mg/m^3 (8-hr average) 712 mg/m^3 (15 minute average)
Pentane	2,950 mg/m^3 (8-hr average)	2,950 mg/m^3 (8-hr average)
Methyl methacrylate	410 mg/m^3 (8-hr average)	205 mg/m^3 (8-hr average) 410 mg/m^3 (15 minute average)
Styrene	426 mg/m^3 (8-hr average) 852 mg/m^3 (ceiling limit)	85 mg/m^3 (8-hr average) 170 mg/m^3 (15-minute average) Proposed change: 8.5 mg/m^3 (8-hr average)

Review of the 48-hour average VOC concentrations, as determined by integrated sampling, indicate that of the specific compounds identified (acetone, n-butyl acetate, and pentane), the average 48-hour concentrations were well below the values of the above-cited guidelines.

Furthermore, the minimum reporting limits of < 0.32 mg/m^3 for methyl methacrylate and< 0.068 mg/m^3 for styrene, are below the above-cited guidelines.

The direct-reading measurements described in 3.1.4 indicated wide, temporary fluctuations in VOC concentrations at the test locations relative to the corresponding 48-hour average concentrations. As a precaution, VOC concentrations should be minimized where possible.

Each test location had unidentified VOCs, ranging in concentration from 0.120 to 0.629 mg/m^3 (approximately 27 to 147 ppb). The laboratory could not provide information on the identity of the compounds that fall into this category, however, laboratory staff indicated that they fall under the broad range of solvent blends such as mineral spirits and Stoddard Solvent. Note that many types of VOCs which are known to have toxic properties were included in the compound search and were reported by the laboratory as non-detect.

The greatest total VOC concentrations, as determined by integrated sampling, including any unidentified VOCs, were in the multi-level student group work areas as compared with L40C and L40D; presumably the use of VOC-containing products both inside and outside the spray booth (e.g., adhesives, paints and coatings), and possibly hot wire cutting operations on the 3rd floor, contribute to the observed VOC concentrations in the multi-level student group work areas.

As noted above, two VOCs associated with 3D printing, methyl methacrylate and styrene, were non-detect in all of the samples.

3.2.2 Results of Integrated Air Sampling for Aldehydes in L40

The results of integrated air sampling for aldehydes are summarized in Table 2 below in both ppb (concentration by volume) and mg/m^3 (concentration by mass) units.

Table 2. Aldehyde Sampling Results
Room L40D
Harvard University Graduate School of Design, 48 Quincy St., Cambridge, Massachusetts
12:40 pm to 7:22 pm, December 6, 2018

Constituent	**Concentration (mg/m^3/ppb)**
Acetaldehyde	0.0036 / 2
Acetone	0.053 / 22
Formaldehyde	0.0055 / 4.5
Methyl Ethyl Ketone (MEK)	0.0038 / 1.3
NOTES: The following additional aldehydes were included in the analysis and results were non-detect: 2,5-Dimethylbenzaldehyde; Benzaldehyde; Butyraldehyde; Hexanaldehyde; Isolvaleraldehyde; Propionaldehyde; Valeraldehyde; m-,p- and o-Tolualdehyde	

Note that acetone and methyl ethyl ketone are included in the scope of the aldehyde sample analysis. The acetone and methyl ethyl ketone results were very consistent with results obtained using the VOC integrated air sampling method:

- The acetone results in L40 using the aldehyde sampling medium were the same as those obtained in L40D using the organic vapor sampling medium.
- The aldehyde sampling method has lower minimum reporting limits than the VOC sampling method; methyl ethyl ketone was detected on the aldehyde sample, at a concentration below the reporting limit of the VOC sampling method.

The only aldehydes detected above the minimum reporting limits were acetaldehyde and formaldehyde.

Exposure Guidelines

Of the four constituents identified by the aldehyde sampling, the following exposure guidelines have been published:

ASTDR MRLs. MRLs were published for **acetone** and **formaldehyde** as follows:

Type of MRL	**Acetone**	**Formaldehyde**
Acute exposure (1 to 14 days)	26 ppm (26,000 ppb)	0.04 ppm (40 ppb)
Intermediate exposure (15 to 364 days)	13 ppm (13,000 ppb)	0.03 ppm (30 ppb)
Chronic exposure (1 year or longer)	13 ppm (13,000 ppb)	0.008 ppm (8 ppb)

The formaldehyde concentration in L40, measured over a period of approximately 6.75 hours, was 4.5 ppb which is less than the MRLs for formaldehyde. As noted previously, the acetone monitoring results are well below the corresponding MRLs.

US EPA RfC. RfCs were published for **acetaldehyde** and **methyl ethyl ketone** of 0.009 mg/m^3 and 5 mg/m^3, respectively.

OSHA and ACGIH occupational exposure limits:

Constituent	**OSHA**	**ACGIH**
Acetaldehyde	360 mg/m3 (8-hr average)	45 mg/m^3 (ceiling limit)
Acetone	2,400 mg/m^3 (8-hr average)	594 mg/m^3 (8-hr average) 1,187 mg/m^3 (15 minute average)
Formaldehyde	0.75 ppm (8-hr average) 2 ppm (15-minute average)	0.12 mg/m^3 (8-hr average) 0.37 mg/m^3 (15 minute average)
Methyl Ethyl Ketone (MEK)	590 mg/m^3 (8-hr average)	590 mg/m^3 (8-hr average) 885 mg/m^3 (15 minute average)

The results indicate that of the various constituents detected in the aldehyde sample, the average 6.75-hour concentrations were below the values of the above-cited guidelines.

Acetaldehyde and formaldehyde are suspect or known carcinogens, respectively; therefore, although the measured concentrations were very low, exposure should be minimized where possible. The local exhaust ventilation in L40 and associated rooms is likely very helpful for minimizing potential emissions due to thermal degradation of materials during laser cutting.

4.0 SUMMARY AND RECOMMENDATIONS

An initial assessment of air quality in Gund Hall was conducted, specifically to address potential air constituents associated with fabrication activities. The test locations included selected areas where fabrication takes place, and in a reference location (L02) for comparison.

UFP – UFP measurements were consistently higher in all fabrication areas in comparison with the control location (L02). There are no guidelines for acceptable UFP concentrations in association with PLA 3D printing. Peak UFP concentrations were greatest at the 2nd floor-near the spray booth test location, suggesting that activities in or around the spray both may contribute to UFP concentrations in that location. Research has suggested a relationship between UFP and adverse health effects due to the potential of these small particles to enter and penetrate the lung tissue. Therefore, UFP concentrations should be minimized where possible.

$PM_{2.5}$ – The maximum $PM_{2.5}$ concentrations in all multi-level student group work areas, L40 and L40C were below the IAQ guideline cited for this constituent, while the maximum concentration in the wood shop (L32) slightly exceeded this guideline. This finding is consistent with $PM_{2.5}$ being associated with larger-sized particles that may be encountered when handling powders or cutting wood in the wood shop areas, as compared with 3D printing, laser cutting and during this study, spray booth activities.

PM_{10} – The maximum PM_{10} concentrations in all multi-level student group work areas, L40 and L40C were below the guideline for this constituent, while the maximum concentration in the wood shop are (L32) exceeded this guideline. This finding is again consistent with larger-sized particles that may be encountered when handling powders or cutting wood in the wood shop areas.

TVOCs - With the highest maximum TVOC concentrations observed in the control location (L02), and the second highest concentrations being observed at the 2nd floor-near the spray booth location, it appears that multiple sources of TVOCs make it difficult to isolate the impact of 3D printing and/or laser cutting operations on TVOC concentrations overall. Another concern is identifying the source of TVOCs that impacted air quality in the control location at the time of the measurements.

As determined from direct-reading measurements, TVOC concentrations fluctuated to varying degrees in the test locations. For example: in the control location, TVOC concentrations ranged from non-detect (< 20 ppb) to > 8,000 ppb; at the 2nd floor-near the spray booth location, from 263 ppb to > 4,000 ppb; at the 3rd floor center location from 331 ppb to 2,423 ppb; and in L40 from 210 ppb to 1,470 ppb.

VOC Integrated Sampling –No elevated concentrations of known, toxic VOCs were identified on the air samples. Methyl methacrylate and styrene, which have been associated with PLA and ABS filament printing, respectively, were non-detect on all of the samples. The types of VOCs identified may be associated with paints, coatings, adhesives, markers, etc. and are not necessarily attributable to 3D printing and laser cutting activities.

Aldehydes Integrated Sampling in L40 – This sampling was conducted to assess potential thermal decomposition products associated with laser cutting, and low concentrations of formaldehyde and acetaldehyde were detected on the sample. Since these constituents are potential irritants and respectively are designated as confirmed or suspect carcinogens, exposures should be maintained as low as possible.

Recommendations

Based on observations and results, TRC recommends the following:

1. Investigate possible sources of VOCs impacting L02. The possibility of VOCs being entrained into the supply air servicing this location should be ruled out. Activities in L02 should also be reviewed and considered.

2. Since the health effects of UFP have not been established at this time, as a long-term goal, potential exposure to UFP emissions should be minimized as follows:

   - Consider placing 3D printers (in groups or individually) in ventilated enclosures. Review of the literature indicates that ventilated enclosures are substantially more efficient at reducing UFP emissions from 3D printers than the housing and doors provided by manufacturers.

   - Note that UFP emissions may vary with different printers and filaments (e.g., color, material, density, type and brand, nozzle and extrusion temperatures may affect emission rates). Consider establishing requirements regarding the types of filaments in use, and/or use printers and filaments that have been tested and verified to have low emissions.

   - Set nozzle temperatures at the lower end of the suggested temperature range for filament materials.

   - Encourage students not to sit or stand in close proximity to operating equipment.

   This will also help to minimize potential VOC emissions associated with 3D printing.

3. The laser cutting equipment is provided with engineering controls / local exhaust ventilation. As a measure to further reduce emissions associated with laser cutting, consider requiring extended cooling times post-cutting prior to opening the cutting enclosure.

4. The 2nd floor spray booth is not fully enclosed for the most efficient capture efficiency. Capture efficiency is typically enhanced if the booth is enclosed on the top, bottom and sides, with the exhaust slot(s) fitted into a solid back and access through the open face of the booth. In addition, the 3rd floor area where hot wire cutting is performed should be reviewed for usage methods that ensure maximum capture efficiency.

   Better enclosure of the spray area may also help to reduce fluctuations in TVOC concentrations in the multi-level student group work areas.

5.0 LIMITATIONS

No expressed or implied representation or warranty is included in this assessment except that the services were performed within the limits of the scope of work authorized by the client and the encountered site conditions.

APPENDIX A:

Direct-reading Measurements Summary Statistics

Direct-reading Measurements Summary Statistics
Harvard University Graduate School of Design, 48 Quincy St., Cambridge, Massachusetts
December 6, 2018

Constituent	Metric	Location							
		2nd FL Near Spray Booth	3rd FL Center	4th FL Near S. Restrooms	L40	L40C	L02 - CONTROL	L33 and L35	L32
TVOCs (ppb)	90th percentile	825	1187	659	856	370	1184	---	---
	Average	526	726	571	542	344	461	---	---
	Minimum	263	331	453	210	288	ND (<20)	---	---
	Maximum	4467	2423	771	1470	391	8791	---	---
Ultrafine Particles (pt/cc)	90th percentile	14872	4827	5119	5885	3443	1856	---	---
	Average	7987	3974	3466	5031	3108	1244	---	---
	Minimum	4463	3102	2559	3504	2582	729	---	---
	Maximum	17648	5444	5679	6447	4995	2504	---	---
$PM_{2.5}$ (mg/m^3)	90th percentile	0.009	0.005	0.008	0.008	0.010	0.004	---	0.036
	Average	0.007	0.004	0.005	0.004	0.006	0.001	---	0.019
	Minimum	0.003	0.003	0.002	0.000	0.004	ND (< 0.001)	---	0.003
	Maximum	0.031	0.009	0.012	0.034	0.015	0.017	---	0.083
PM_{10} (mg/m^3)	90th percentile	0.013	0.009	0.012	0.015	0.014	0.011	0.045	0.060
	Average	0.010	0.007	0.008	0.008	0.008	0.004	0.028	0.030
	Minimum	0.005	0.005	0.004	0.001	0.005	ND (< 0.001)	0.008	0.005
	Maximum	0.040	0.013	0.017	0.071	0.026	0.043	0.245	0.128

--- indicates no measurement of that constituent in the test location
ND is non-detect

APPENDIX B:

Methods

Integrated Air Sampling for Aldehydes

One area air sample for a range of aldehydes was collected in L40 using a Gilian personal sampling pump. The sample was collected by drawing air through a 2,4-Dinitrophenylhydrazine (DNPH)-coated silica gel cartridge at an air sampling flow rate of approximately 1 liter per minute (LPM). The flow rates were determined prior to and immediately following the sampling periods using a calibrated rotameter. A field blank also was prepared. The sample and the field blank were sent by overnight mail to the Wisconsin Occupational Health Laboratory (WOHL), an American Industrial Hygiene Association accredited laboratory in Madison, Wisconsin. Analysis of aldehydes was performed in accordance with U.S. EPA Method TO11A.

Airborne Particulate

In L32 to L35, direct-reading measurements of airborne particulate as PM_{10} were performed using a TSI Incorporated (TSI) DustTrak Model 8520 Aerosol Monitor. The instrument measures PM_{10} by drawing air through a 10-micron inlet and passing the sampled air through a light-scattering laser photometer. It has a stated accuracy of ±0.1% of the reading or ±0.001 mg/m^3, whichever is greater. The instrument is calibrated annually by the manufacturer in accordance with International Organization for Standardization (ISO) standard 12103-2, and is zeroed in the field prior to use in accordance with manufacturer recommendations. The instrument recorded data at a preset one-minute intervals, and the collected data was downloaded to a computer using TSI Incorporated TrakPro software and analyzed and charted using Microsoft Excel.

Continuous measurements of airborne particulate as $PM_{2.5}$ and PM_{10} were performed using a TSI DustTrak Model DRX Aerosol Monitor. The instrument measures airborne particulate by drawing the sampled air through a light-scattering laser photometer. It has a stated accuracy of ±0.1% of the reading or ±0.001 mg/m^3, whichever is greater. The instrument is calibrated annually by the manufacturer in accordance with International Organization for Standardization (ISO) standard 12103-2, and is zeroed in the field prior to use in accordance with manufacturer recommendations. The instrument recorded data at preset one-minute intervals, and the collected data was downloaded to a computer using TSI Incorporated TrakPro software and analyzed and charted using Microsoft Excel.

Ultrafine Particles

Continuous measurements of ultrafine particles (0.02 – 1µm aerodynamic diameter) were performed using the TSI P-Trak Ultrafine Particle Counters (UPC). The instrument draws air through an inlet using a pump. The particles pass through an alcohol-soaked cylinder and become saturated. The alcohol-saturated particles will then pass through a condenser and grow in size. The droplets continue to pass through a laser beam, and the particle concentration is determined by the laser flashes. The instrument is calibrated annually by the manufacturer and is zeroed in the field prior to use in accordance with manufacturer recommendations. The instrument recorded data at preset one-minute intervals, and the collected data was downloaded to a computer using TSI Incorporated TrakPro software and analyzed and charted using Microsoft Excel.

Total Volatile Organic Compounds (TVOCs)

Continuous measurements of TVOCs were performed using a RAE Systems Inc. ppbRAE VOC Monitor, model PGM-7240. The instrument is a photoionization detector that detects VOCs by ionization of the molecules using radiation from an internal 10.6 eV ultraviolet lamp. The instrument response to a particular VOC depends on the ionization energy of the VOC relative to the energy of the ultraviolet lamp. The instrument cannot distinguish different VOCs in the sampled air and provides a cumulative response. The ppbRAE is sensitive to a few parts per billion (isobutylene) and its accuracy is the larger of ±20 ppb or 10% of the reading. The instrument was calibrated prior to use in the field using standard isobutylene calibration gas. The instrument recorded data at preset one-minute intervals, and the collected data was downloaded and analyzed and charted using Microsoft Excel.

Integrated Air Sampling for Specific and Total VOCs

Air samples for volatile organic compounds were collected using the 3M Organic Vapor Monitor 3520, an organic vapor passive badge, over a sampling period of approximately 48 hours. Area samples were generally located at breathing zone height. A field blank was prepared for quality control purposes. The samples and field blank were sealed in the original containers that were provided by the manufacturer, and sent by overnight mail to the Wisconsin Occupational Health Laboratory (WOHL), an American Industrial Hygiene Association (AIHA) accredited laboratory located in Madison, Wisconsin. The samples and field blank were analyzed for VOCs based on OSHA methods 1001, 1002, 1004, 1005 and 111.

Appendix C-1: WOHL Laboratory Report – VOC Sample Analysis

Wisconsin Occupational Health Laboratory
WISCONSIN STATE LABORATORY OF HYGIENE
UNIVERSITY OF WISCONSIN-MADISON

2601 Agriculture Drive
Madison, WI 53718
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MARLEY CARROLL
TRC ENVIRONMENTAL
300 WILDWOOD AVE
WOBURN, MA 01801

Lab Workorder ID	423502
Visit/Project ID	322071 HU GRAD SCHOOL OF DESIG
PO	
Received	December 11, 2018
Reported	December 21, 2018
Report ID	6077915
Previous Report IDs	

Dear MARLEY CARROLL:

Enclosed are the analytical results for sample(s) received by the laboratory on December 11, 2018. All samples received were acceptable, results were not blank corrected, and all quality control met laboratory standards unless otherwise noted in the body of the report.

If you have any questions concerning this report, please feel free to contact the lab.

Sincerely,

Steve Strebel, Laboratory Director

Analyst - BRANDON NOBLE

Wisconsin Occupational Health Laboratory
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Final Report

Lab ID: **423502001**	Sample ID: **VQ5931 2ND FL SPRAY BOOTH**	Media: **3M 3520 OVM**
Sampling Date: **12/5/2018**	Matrix: **Air**	Sampled Time: **2920 M**

						RESULT			
Analyte	**Method**	**Analysis Date**	**Air Volume**	**Reporting Limit**	**Front**	**Rear**	**Total**	**Air Concentration**	**TWA**
Acetone	OSHA 1001,1002, 1004,1005,111	12/19/2018	117 L	4.8 ug	31 ug	<4.8 ug	31 ug	0.26 mg/m3	0.11 ppm
Benzene		12/19/2018	104 L	11 ug	<11 ug	<11 ug	<11 ug	<0.11 mg/m3	<0.033 ppm
Bromopropane (1-)		12/19/2018	92.6 L	8.1 ug	<8.1 ug	<8.1 ug	<8.1 ug	<0.088 mg/m3	<0.017 ppm
Butyl Acetate (n-)		12/19/2018	92.3 L	5.4 ug	5.6 ug	<5.4 ug	5.6 ug	0.061 mg/m3	0.013 ppm
Chlorobenzotrifluoride (4-)		12/19/2018	75.3 L	16 ug	<16 ug	<16 ug	<16 ug	<0.21 mg/m3	<0.029 ppm
Ethyl Benzene		12/19/2018	79.7 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.064 mg/m3	<0.015 ppm
Ethyl acetate		12/19/2018	101 L	5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	<0.054 mg/m3	<0.015 ppm
Limonene		12/19/2018	63.9 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.080 mg/m3	<0.014 ppm
Methyl Amyl Ketone (n-)		12/19/2018	81.5 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.059 mg/m3	<0.013 ppm
Methyl Ethyl Ketone (MEK)		12/19/2018	106 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.045 mg/m3	<0.015 ppm
Methyl isobutyl ketone		12/19/2018	87.6 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.055 mg/m3	<0.013 ppm
Methyl methacrylate		12/19/2018	92.9 L	29 ug	<29 ug	<29 ug	<29 ug	<0.31 mg/m3	<0.076 ppm
Methylene chloride		12/19/2018	111 L	16 ug	<16 ug	<16 ug	<16 ug	<0.14 mg/m3	<0.042 ppm
Pentane		12/19/2018	103 L	3.9 ug	<3.9 ug	<3.9 ug	<3.9 ug	<0.038 mg/m3	<0.013 ppm
Pentanone (2-)		12/19/2018	96.4 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.050 mg/m3	<0.014 ppm
Styrene		12/19/2018	84.4 L	5.7 ug	<5.7 ug	<5.7 ug	<5.7 ug	<0.068 mg/m3	<0.016 ppm
Tetrachloroethene		12/19/2018	82.6 L	9.6 ug	<9.6 ug	<9.6 ug	<9.6 ug	<0.12 mg/m3	<0.017 ppm
Toluene		12/19/2018	91.7 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.056 mg/m3	<0.015 ppm
Total VOC as hexane		12/19/2018	93.4 L	3.9 ug	78 ug	12 ug	90 ug	0.96 mg/m3	0.27 ppm
Trichloroethene		12/19/2018	90.8 L	8.7 ug	<8.7 ug	<8.7 ug	<8.7 ug	<0.096 mg/m3	<0.018 ppm
Trimethylbenzenes (isomers)		12/19/2018	76.8 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.066 mg/m3	<0.014 ppm
Xylene (total)		12/19/2018	79.7 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.064 mg/m3	<0.015 ppm
n-Hexane		12/19/2018	93.4 L	3.9 ug	<3.9 ug	<3.9 ug	<3.9 ug	<0.042 mg/m3	<0.012 ppm

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Final Report

Lab ID: **423502002**	Sample ID: **VQ5885 3RD FL CENTER**	Media: **3M 3520 OVM**
Sampling Date: **12/5/2018**	Matrix: **Air**	Sampled Time: **2904 M**

						RESULT			
Analyte	**Method**	**Analysis Date**	**Air Volume**	**Reporting Limit**	**Front**	**Rear**	**Total**	**Air Concentration**	**TWA**
Acetone	OSHA 1001,1002, 1004,1005,111	12/19/2018	116 L	4.8 ug	18 ug	<4.8 ug	18 ug	0.15 mg/m3	0.065 ppm
Benzene		12/19/2018	103 L	11 ug	<11 ug	<11 ug	<11 ug	<0.11 mg/m3	<0.033 ppm
Bromopropane (1-)		12/19/2018	92.1 L	8.1 ug	<8.1 ug	<8.1 ug	<8.1 ug	<0.088 mg/m3	<0.017 ppm
Butyl Acetate (n-)		12/19/2018	91.8 L	5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	<0.059 mg/m3	<0.012 ppm
Chlorobenzotrifluoride (4-)		12/19/2018	74.9 L	16 ug	<16 ug	<16 ug	<16 ug	<0.21 mg/m3	<0.029 ppm
Ethyl Benzene		12/19/2018	79.3 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.064 mg/m3	<0.015 ppm
Ethyl acetate		12/19/2018	100 L	5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	<0.054 mg/m3	<0.015 ppm
Limonene		12/19/2018	63.6 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.080 mg/m3	<0.014 ppm
Methyl Amyl Ketone (n-)		12/19/2018	81.0 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.059 mg/m3	<0.013 ppm
Methyl Ethyl Ketone (MEK)		12/19/2018	105 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.046 mg/m3	<0.015 ppm
Methyl isobutyl ketone		12/19/2018	87.1 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.055 mg/m3	<0.013 ppm
Methyl methacrylate		12/19/2018	92.3 L	29 ug	<29 ug	<29 ug	<29 ug	<0.31 mg/m3	<0.077 ppm
Methylene chloride		12/19/2018	110 L	16 ug	<16 ug	<16 ug	<16 ug	<0.15 mg/m3	<0.042 ppm
Pentane		12/19/2018	103 L	3.9 ug	<3.9 ug	<3.9 ug	<3.9 ug	<0.038 mg/m3	<0.013 ppm
Pentanone (2-)		12/19/2018	95.8 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.050 mg/m3	<0.014 ppm
Styrene		12/19/2018	83.9 L	5.7 ug	<5.7 ug	<5.7 ug	<5.7 ug	<0.068 mg/m3	<0.016 ppm
Tetrachloroethene		12/19/2018	82.2 L	9.6 ug	<9.6 ug	<9.6 ug	<9.6 ug	<0.12 mg/m3	<0.017 ppm
Toluene		12/19/2018	91.2 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.056 mg/m3	<0.015 ppm
Total VOC as hexane		12/19/2018	92.9 L	3.9 ug	52 ug	7.4 ug	59 ug	0.64 mg/m3	0.18 ppm
Trichloroethene		12/19/2018	90.3 L	8.7 ug	<8.7 ug	<8.7 ug	<8.7 ug	<0.096 mg/m3	<0.018 ppm
Trimethylbenzenes (isomers)		12/19/2018	76.4 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.067 mg/m3	<0.014 ppm
Xylene (total)		12/19/2018	79.3 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.064 mg/m3	<0.015 ppm
n-Hexane		12/19/2018	92.9 L	3.9 ug	<3.9 ug	<3.9 ug	<3.9 ug	<0.042 mg/m3	<0.012 ppm

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Final Report

Lab ID: **423502003**	Sample ID: **VQ2855 4TH FL S. RESTROOMS**	Media: **3M 3520 OVM**
Sampling Date: **12/5/2018**	Matrix: **Air**	Sampled Time: **2912 M**

						RESULT			
Analyte	**Method**	**Analysis Date**	**Air Volume**	**Reporting Limit**	**Front**	**Rear**	**Total**	**Air Concentration**	**TWA**
Acetone	OSHA 1001,1002, 1004,1005,111	12/19/2018	117 L	4.8 ug	16 ug	<4.8 ug	16 ug	0.14 mg/m3	0.058 ppm
Benzene		12/19/2018	103 L	11 ug	<11 ug	<11 ug	<11 ug	<0.11 mg/m3	<0.033 ppm
Bromopropane (1-)		12/19/2018	92.3 L	8.1 ug	<8.1 ug	<8.1 ug	<8.1 ug	<0.088 mg/m3	<0.017 ppm
Butyl Acetate (n-)		12/19/2018	92.0 L	5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	<0.059 mg/m3	<0.012 ppm
Chlorobenzotrifluoride (4-)		12/19/2018	75.1 L	16 ug	<16 ug	<16 ug	<16 ug	<0.21 mg/m3	<0.029 ppm
Ethyl Benzene		12/19/2018	79.5 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.064 mg/m3	<0.015 ppm
Ethyl acetate		12/19/2018	100 L	5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	<0.054 mg/m3	<0.015 ppm
Limonene		12/19/2018	63.8 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.080 mg/m3	<0.014 ppm
Methyl Amyl Ketone (n-)		12/19/2018	81.2 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.059 mg/m3	<0.013 ppm
Methyl Ethyl Ketone (MEK)		12/19/2018	106 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.045 mg/m3	<0.015 ppm
Methyl isobutyl ketone		12/19/2018	87.4 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.055 mg/m3	<0.013 ppm
Methyl methacrylate		12/19/2018	92.6 L	29 ug	<29 ug	<29 ug	<29 ug	<0.31 mg/m3	<0.076 ppm
Methylene chloride		12/19/2018	110 L	16 ug	<16 ug	<16 ug	<16 ug	<0.14 mg/m3	<0.042 ppm
Pentane		12/19/2018	103 L	3.9 ug	4.5 ug	<3.9 ug	4.5 ug	0.044 mg/m3	0.015 ppm
Pentanone (2-)		12/19/2018	96.1 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.050 mg/m3	<0.014 ppm
Styrene		12/19/2018	84.2 L	5.7 ug	<5.7 ug	<5.7 ug	<5.7 ug	<0.068 mg/m3	<0.016 ppm
Tetrachloroethene		12/19/2018	82.4 L	9.6 ug	<9.6 ug	<9.6 ug	<9.6 ug	<0.12 mg/m3	<0.017 ppm
Toluene		12/19/2018	91.4 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.056 mg/m3	<0.015 ppm
Total VOC as hexane		12/19/2018	93.2 L	3.9 ug	64 ug	9.9 ug	74 ug	0.79 mg/m3	0.22 ppm
Trichloroethene		12/19/2018	90.6 L	8.7 ug	<8.7 ug	<8.7 ug	<8.7 ug	<0.096 mg/m3	<0.018 ppm
Trimethylbenzenes (isomers)		12/19/2018	76.6 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.067 mg/m3	<0.014 ppm
Xylene (total)		12/19/2018	79.5 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.064 mg/m3	<0.015 ppm
n-Hexane		12/19/2018	93.2 L	3.9 ug	<3.9 ug	<3.9 ug	<3.9 ug	<0.042 mg/m3	<0.012 ppm

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Final Report

Lab ID: **423502004**	Sample ID: **VQ5886 L40C**	Media: **3M 3520 OVM**
Sampling Date: **12/5/2018**	Matrix: **Air**	Sampled Time: **2895 M**

						RESULT			
Analyte	**Method**	**Analysis Date**	**Air Volume**	**Reporting Limit**	**Front**	**Rear**	**Total**	**Air Concentration**	**TWA**
Acetone	OSHA 1001,1002, 1004,1005,111	12/19/2018	116 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.041 mg/m3	<0.017 ppm
Benzene		12/19/2018	103 L	11 ug	<11 ug	<11 ug	<11 ug	<0.11 mg/m3	<0.034 ppm
Bromopropane (1-)		12/19/2018	91.8 L	8.1 ug	<8.1 ug	<8.1 ug	<8.1 ug	<0.088 mg/m3	<0.018 ppm
Butyl Acetate (n-)		12/19/2018	91.5 L	5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	<0.059 mg/m3	<0.012 ppm
Chlorobenzotrifluoride (4-)		12/19/2018	74.7 L	16 ug	<16 ug	<16 ug	<16 ug	<0.21 mg/m3	<0.029 ppm
Ethyl Benzene		12/19/2018	79.0 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.065 mg/m3	<0.015 ppm
Ethyl acetate		12/19/2018	99.9 L	5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	<0.054 mg/m3	<0.015 ppm
Limonene		12/19/2018	63.4 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.080 mg/m3	<0.014 ppm
Methyl Amyl Ketone (n-)		12/19/2018	80.8 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.059 mg/m3	<0.013 ppm
Methyl Ethyl Ketone (MEK)		12/19/2018	105 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.046 mg/m3	<0.015 ppm
Methyl isobutyl ketone		12/19/2018	86.9 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.055 mg/m3	<0.013 ppm
Methyl methacrylate		12/19/2018	92.1 L	29 ug	<29 ug	<29 ug	<29 ug	<0.32 mg/m3	<0.077 ppm
Methylene chloride		12/19/2018	110 L	16 ug	<16 ug	<16 ug	<16 ug	<0.15 mg/m3	<0.042 ppm
Pentane		12/19/2018	102 L	3.9 ug	12 ug	<3.9 ug	12 ug	0.12 mg/m3	0.040 ppm
Pentanone (2-)		12/19/2018	95.5 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.050 mg/m3	<0.014 ppm
Styrene		12/19/2018	83.7 L	5.7 ug	<5.7 ug	<5.7 ug	<5.7 ug	<0.068 mg/m3	<0.016 ppm
Tetrachloroethene		12/19/2018	81.9 L	9.6 ug	<9.6 ug	<9.6 ug	<9.6 ug	<0.12 mg/m3	<0.017 ppm
Toluene		12/19/2018	90.9 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.056 mg/m3	<0.015 ppm
Total VOC as hexane		12/19/2018	92.6 L	3.9 ug	22 ug	<3.9 ug	22 ug	0.24 mg/m3	0.067 ppm
Trichloroethene		12/19/2018	90.0 L	8.7 ug	<8.7 ug	<8.7 ug	<8.7 ug	<0.097 mg/m3	<0.018 ppm
Trimethylbenzenes (isomers)		12/19/2018	76.1 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.067 mg/m3	<0.014 ppm
Xylene (total)		12/19/2018	79.0 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.065 mg/m3	<0.015 ppm
n-Hexane		12/19/2018	92.6 L	3.9 ug	<3.9 ug	<3.9 ug	<3.9 ug	<0.042 mg/m3	<0.012 ppm

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Final Report

Lab ID: **423502005** | Sample ID: **VQ5928 L40D** | Media: **3M 3520 OVM**
Sampling Date: **12/7/2018** | Matrix: **Air** | Sampled Time: **2892 M**

						RESULT			
Analyte	**Method**	**Analysis Date**	**Air Volume**	**Reporting Limit**	**Front**	**Rear**	**Total**	**Air Concentration**	**TWA**
Acetone	OSHA 1001,1002, 1004,1005,111	12/19/2018	116 L	4.8 ug	6.1 ug	<4.8 ug	6.1 ug	0.053 mg/m3	0.022 ppm
Benzene		12/19/2018	103 L	11 ug	<11 ug	<11 ug	<11 ug	<0.11 mg/m3	<0.034 ppm
Bromopropane (1-)		12/19/2018	91.7 L	8.1 ug	<8.1 ug	<8.1 ug	<8.1 ug	<0.088 mg/m3	<0.018 ppm
Butyl Acetate (n-)		12/19/2018	91.4 L	5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	<0.059 mg/m3	<0.012 ppm
Chlorobenzotrifluoride (4-)		12/19/2018	74.6 L	16 ug	<16 ug	<16 ug	<16 ug	<0.21 mg/m3	<0.029 ppm
Ethyl Benzene		12/19/2018	79.0 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.065 mg/m3	<0.015 ppm
Ethyl acetate		12/19/2018	99.8 L	5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	<0.054 mg/m3	<0.015 ppm
Limonene		12/19/2018	63.3 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.081 mg/m3	<0.014 ppm
Methyl Amyl Ketone (n-)		12/19/2018	80.7 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.059 mg/m3	<0.013 ppm
Methyl Ethyl Ketone (MEK)		12/19/2018	105 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.046 mg/m3	<0.016 ppm
Methyl isobutyl ketone		12/19/2018	86.8 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.055 mg/m3	<0.014 ppm
Methyl methacrylate		12/19/2018	92.0 L	29 ug	<29 ug	<29 ug	<29 ug	<0.32 mg/m3	<0.077 ppm
Methylene chloride		12/19/2018	110 L	16 ug	<16 ug	<16 ug	<16 ug	<0.15 mg/m3	<0.042 ppm
Pentane		12/19/2018	102 L	3.9 ug	7.0 ug	<3.9 ug	7.0 ug	0.069 mg/m3	0.023 ppm
Pentanone (2-)		12/19/2018	95.4 L	4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	<0.050 mg/m3	<0.014 ppm
Styrene		12/19/2018	83.6 L	5.7 ug	<5.7 ug	<5.7 ug	<5.7 ug	<0.068 mg/m3	<0.016 ppm
Tetrachloroethene		12/19/2018	81.8 L	9.6 ug	<9.6 ug	<9.6 ug	<9.6 ug	<0.12 mg/m3	<0.017 ppm
Toluene		12/19/2018	90.8 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.056 mg/m3	<0.015 ppm
Total VOC as hexane		12/19/2018	92.5 L	3.9 ug	25 ug	<3.9 ug	25 ug	0.27 mg/m3	0.077 ppm
Trichloroethene		12/19/2018	89.9 L	8.7 ug	<8.7 ug	<8.7 ug	<8.7 ug	<0.097 mg/m3	<0.018 ppm
Trimethylbenzenes (isomers)		12/19/2018	76.1 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.067 mg/m3	<0.014 ppm
Xylene (total)		12/19/2018	79.0 L	5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	<0.065 mg/m3	<0.015 ppm
n-Hexane		12/19/2018	92.5 L	3.9 ug	<3.9 ug	<3.9 ug	<3.9 ug	<0.042 mg/m3	<0.012 ppm

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Final Report

Lab ID: **423502006**	Sample ID: **VQ5900 FB**	Media: **3M 3520 OVM**
Sampling Date: **12/7/2018**	Matrix: **Air**	Sampled Time:

					RESULT				
Analyte	**Method**	**Analysis Date**	**Air Volume**	**Reporting Limit**	**Front**	**Rear**	**Total**	**Air Concentration**	**TWA**
Acetone	OSHA 1001,1002, 1004,1005,111	12/19/2018		4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	n/a	n/a
Benzene		12/19/2018		11 ug	<11 ug	<11 ug	<11 ug	n/a	n/a
Bromopropane (1-)		12/19/2018		8.1 ug	<8.1 ug	<8.1 ug	<8.1 ug	n/a	n/a
Butyl Acetate (n-)		12/19/2018		5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	n/a	n/a
Chlorobenzotrifluoride (4-)		12/19/2018		16 ug	<16 ug	<16 ug	<16 ug	n/a	n/a
Ethyl Benzene		12/19/2018		5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	n/a	n/a
Ethyl acetate		12/19/2018		5.4 ug	<5.4 ug	<5.4 ug	<5.4 ug	n/a	n/a
Limonene		12/19/2018		5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	n/a	n/a
Methyl Amyl Ketone (n-)		12/19/2018		4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	n/a	n/a
Methyl Ethyl Ketone (MEK)		12/19/2018		4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	n/a	n/a
Methyl isobutyl ketone		12/19/2018		4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	n/a	n/a
Methyl methacrylate		12/19/2018		29 ug	<29 ug	<29 ug	<29 ug	n/a	n/a
Methylene chloride		12/19/2018		16 ug	<16 ug	<16 ug	<16 ug	n/a	n/a
Pentane		12/19/2018		3.9 ug	<3.9 ug	<3.9 ug	<3.9 ug	n/a	n/a
Pentanone (2-)		12/19/2018		4.8 ug	<4.8 ug	<4.8 ug	<4.8 ug	n/a	n/a
Styrene		12/19/2018		5.7 ug	<5.7 ug	<5.7 ug	<5.7 ug	n/a	n/a
Tetrachloroethene		12/19/2018		9.6 ug	<9.6 ug	<9.6 ug	<9.6 ug	n/a	n/a
Toluene		12/19/2018		5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	n/a	n/a
Total VOC as hexane		12/19/2018		3.9 ug	<3.9 ug	<3.9 ug	<3.9 ug	n/a	n/a
Trichloroethene		12/19/2018		8.7 ug	<8.7 ug	<8.7 ug	<8.7 ug	n/a	n/a
Trimethylbenzenes (isomers)		12/19/2018		5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	n/a	n/a
Xylene (total)		12/19/2018		5.1 ug	<5.1 ug	<5.1 ug	<5.1 ug	n/a	n/a
n-Hexane		12/19/2018		3.9 ug	<3.9 ug	<3.9 ug	<3.9 ug	n/a	n/a

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Final Report

Abbreviations:

mg = milligrams	ppm or ppmv = parts per million	/m3 = per cubic meter
ug = micrograms	ppb or ppbv = parts per billion	ng = nanograms

< Less Than. The analyte, if present, is at a level too low to be accurately quantitated by the method used

End of Analytical Report

The results in this report apply only to the samples, specifically listed above, and tested at the Wisconsin Occupational Health Laboratory

WISCONSIN OCCUPATIONAL HEALTH LABORATORY (WOHL) SAMPLE SUBMISSION FORM

Bill To TRC Environmental
21 Griffin Road North
Windsor, CT 06095

WOHL COMP#

Phone # 781-999-0794

FAX #

Email Address mcarroll@trcsolutions.com

Send Results To ATTN: Marley Carroll
mcarroll@trcsolutions.com

Project 322071 HU Grad School of Design

P.O. #

Date Sampled 12/5/18 - 12/7/18

Turnaround: ☐ RUSH ☐ PRIORITY ☒ NORMAL
{ must be prearranged }

Record on 12/4/18

SPECIAL INSTRUCTIONS

• PLEASE GROUP SAMPLES BY MEDIA USED AND ANALYSIS REQUESTED. •

LAB USE ONLY WOHL SAMPLE #	CUSTOMER FIELD #	SAMPLE MEDIA	WIPE SAMPLES SIZE OF AREA WIPED EX: 2 IN x 2 IN	FOR AIR SAMPLES ONLY TIME ON	TIME OFF	TOTAL TIME (MINS)	FLOW RATE (L/MIN)	VOLUME (LITERS)	ANALYSIS REQUEST
		3520		12/5/18	12/7/18				
	VQ 5931 2nd FL Spray Booth	Badge		4:58p	5:38p	2920			VOC scan "A" w/ styrene and
	VQ 5885 3rd FL Center			5:19p	5:43p	2904			methacrylate
	VQ 2855 4th FL S. Restrooms			5:12p	5:44p	2912			
	VQ 5886 L40C			5:20p	5:44p	2895			
	VQ 5928 L40D			5:36p	5:48p	2892			
	VQ 5900 FB			—	—	—			
	Ald-L40	Seppak		12:49p	7:22p	402	1.04	418	Aldehyde Scan TO-11
	Ald-FB			—	—	—	—	—	

CHAIN OF CUSTODY: Relinquished Marley Carroll MC Date 12/10/18 Received Date

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Madison, WI 53718

US Postal Service
Wisconsin Occupational Health Lab
PO Box 7996
Madison, WI 53707-7996

Phone 608 224-6210 800 446-0403 ***Sampling Questions*** WOHLsampling@mail.slh.wisc.edu
FAX 608 224-6213 ***Web Page/Order Media*** http://www.slh.wisc.edu/wohl

SAMPLE CONDITION
_____ OK
_____ NOT OK
See Sample Receipt Record

Appendix C-2: List of VOCs Included in Compound Search

Analytes included in solvent scan analysis:

Scan: Solvent Scan A
Media: Large (2) or small (1) charcoal tube, Badge (128)*
Analytes included:

- Acetone
- Benzene
- n-Bromopropane
- n-Butyl Acetate
- 1-Chloro-4-trifluoromethylbenzene (*Chlorobenzo-tri fluoride)*
- Cyclohexane
- Cyclohexanone
- Diisobutyl ketone
- Ethyl Acetate
- Ethyl Alcohol (*Ethanol)*
- Ethyl Benzene
- Hexane n
- Isopropyl Alcohol (*Isopropanol, 2-propanol*)
- Isopropylbenzene (*Cumene)*
- Limonene
- Methyl Amyl Ketone n-
- Methyl Ethyl Ketone (*MEK, 2-butanone)*
- Methyl isobutyl ketone (*MIBK, hexone, 4-Methyl-2-pentanone)*
- Methylene Chloride
- Methyl Methacrylate
- Pentane
- 2-Pentanone
- Styrene
- 4-tert-Butyltoluene
- Tetrachloroethene (*tetrachloroethylene)*
- Toluene
- Total VOC as hexane (*Naphtha, mineral spirits, Stoddard solvent)*
- Trichloroethene (*trichloroethylene)*
- Trimethylbenzenes
- Xylenes

Appendix D: WOHL Laboratory Report – Aldehyde Sample Analysis

Wisconsin Occupational Health Laboratory
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Web: wohl-lab.org

MARLEY CARROLL
TRC ENVIRONMENTAL
300 WILDWOOD AVE
WOBURN, MA 01801

Lab Workorder ID	423503
Visit/Project ID	322071 HU GRAD SCHOOL OF DESIG
PO	
Received	December 11, 2018
Reported	December 28, 2018
Report ID	6085318
Previous Report IDs	

Dear MARLEY CARROLL:

Enclosed are the analytical results for sample(s) received by the laboratory on December 11, 2018. All samples received were acceptable, results were not blank corrected, and all quality control met laboratory standards unless otherwise noted in the body of the report.

If you have any questions concerning this report, please feel free to contact the lab.

Sincerely,

Steve Strebel, Laboratory Director

Analyst - JOHN GLOWACKI

Wisconsin Occupational Health Laboratory
WISCONSIN STATE LABORATORY OF HYGIENE
UNIVERSITY OF WISCONSIN-MADISON

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Final Report

Lab ID: **423503001** | Sample ID: **ALD-L40** | Media: **DNPH Cartridge (XPOSURE)**
Sampling Date: **12/5/2018** | Matrix: **Air** | Sampled Time:

						RESULT			
Analyte	**Method**	**Analysis Date**	**Air Volume**	**Reporting Limit**	**Front**	**Rear**	**Total**	**Air Concentration**	**TWA**
2,5-Dimethylbenzaldehyde	EPA TO11A	12/27/2018	418 L	1.6 ug			<1.6 ug	<0.0038 mg/m3	<0.00070 ppm
Acetaldehyde		12/27/2018	418 L	0.80 ug			1.5 ug	0.0036 mg/m3	0.0020 ppm
Acetone		12/27/2018	418 L	1.6 ug			22 ug	0.053 mg/m3	0.022 ppm
Benzaldehyde		12/27/2018	418 L	0.80 ug			<0.80 ug	<0.0019 mg/m3	<0.00044 ppm
Butyraldehyde		12/27/2018	418 L	1.6 ug			<1.6 ug	<0.0038 mg/m3	<0.0013 ppm
Formaldehyde		12/27/2018	418 L	0.80 ug			2.3 ug	0.0055 mg/m3	0.0045 ppm
Hexanaldehyde		12/27/2018	418 L	1.6 ug			<1.6 ug	<0.0038 mg/m3	<0.00093 ppm
Isovaleraldehyde		12/27/2018	418 L	1.6 ug			<1.6 ug	<0.0038 mg/m3	<0.0011 ppm
Methyl Ethyl Ketone (MEK)		12/27/2018	418 L	1.6 ug			1.6 ug	0.0038 mg/m3	0.0013 ppm
Propionaldehyde		12/27/2018	418 L	1.6 ug			<1.6 ug	<0.0038 mg/m3	<0.0016 ppm
Valeraldehyde		12/27/2018	418 L	1.6 ug			<1.6 ug	<0.0038 mg/m3	<0.0011 ppm
m & p-Tolualdehyde		12/27/2018	418 L	1.6 ug			<1.6 ug	<0.0038 mg/m3	<0.00078 ppm
o-Tolualdehyde		12/27/2018	418 L	1.6 ug			<1.6 ug	<0.0038 mg/m3	<0.00078 ppm

Lab ID: **423503002** | Sample ID: **ALD-FB** | Media: **DNPH Cartridge (XPOSURE)**
Sampling Date: **12/7/2018** | Matrix: **Air** | Sampled Time:

						RESULT			
Analyte	**Method**	**Analysis Date**	**Air Volume**	**Reporting Limit**	**Front**	**Rear**	**Total**	**Air Concentration**	**TWA**
2,5-Dimethylbenzaldehyde	EPA TO11A	12/27/2018		1.6 ug			<1.6 ug	n/a	n/a
Acetaldehyde		12/27/2018		0.80 ug			<0.80 ug	n/a	n/a
Acetone		12/27/2018		1.6 ug			<1.6 ug	n/a	n/a
Benzaldehyde		12/27/2018		0.80 ug			<0.80 ug	n/a	n/a
Butyraldehyde		12/27/2018		1.6 ug			<1.6 ug	n/a	n/a

Report ID: 6085318

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Final Report

Lab ID: **423503002**	Sample ID: **ALD-FB**	Media: **DNPH Cartridge (XPOSURE)**
Sampling Date: **12/7/2018**	Matrix: **Air**	Sampled Time:

Analyte	Method	Analysis Date	Air Volume	Reporting Limit	RESULT Front	Rear	Total	Air Concentration	TWA
Formaldehyde		12/27/2018		0.80 ug			<0.80 ug	n/a	n/a
Hexanaldehyde		12/27/2018		1.6 ug			<1.6 ug	n/a	n/a
Isovaleraldehyde		12/27/2018		1.6 ug			<1.6 ug	n/a	n/a
Methyl Ethyl Ketone (MEK)		12/27/2018		1.6 ug			<1.6 ug	n/a	n/a
Propionaldehyde		12/27/2018		1.6 ug			<1.6 ug	n/a	n/a
Valeraldehyde		12/27/2018		1.6 ug			<1.6 ug	n/a	n/a
m & p-Tolualdehyde		12/27/2018		1.6 ug			<1.6 ug	n/a	n/a
o-Tolualdehyde		12/27/2018		1.6 ug			<1.6 ug	n/a	n/a

Abbreviations:
mg = milligrams ppm or ppmv = parts per million /m3 = per cubic meter
ug = micrograms ppb or ppbv = parts per billion ng = nanograms
< Less Than. The analyte, if present, is at a level too low to be accurately quantitated by the method used

End of Analytical Report

The results in this report apply only to the samples, specifically listed above, and tested at the Wisconsin Occupational Health Laboratory

WISCONSIN OCCUPATIONAL HEALTH LABORATORY (WOHL) SAMPLE SUBMISSION FORM

Bill To TRC Environmental
21 Griffin Road North
Windsor, CT 06095

WOHL COMP#

Phone # 781-999-0794

FAX #

Email Address mcarroll@trcsolutions.com

Send Results To ATTN: Marley Carroll
mcarroll@trcsolutions.com

Project 322671 HU Grad School of Design

P.O. #

Date Sampled 12/5/18 - 12/7/18

Turnaround: ☐ RUSH ☐ PRIORITY ☒ NORMAL
{ must be prearranged }

Record on 12/4/18

SPECIAL INSTRUCTIONS

• PLEASE GROUP SAMPLES BY MEDIA USED AND ANALYSIS REQUESTED. •

LAB USE ONLY WOHL SAMPLE #	CUSTOMER FIELD #	SAMPLE MEDIA	WIPE SAMPLES SIZE OF AREA WIPED EX: 2 IN x 2 IN	FOR AIR SAMPLES ONLY TIME ON 12/5/18	TIME OFF 12/7/18	TOTAL TIME (MINS)	FLOW RATE (L/MIN)	VOLUME (LITERS)	ANALYSIS REQUEST
	VQ 5931 2nd FL Spray Booth	3520 Badge		4:58p	5:38p	2920			VOC scan "A" w/ styrene and
	VQ 5885 3rd FL Center			5:19p	5:43p	2904			methacrylate
	VQ 2855 4th FL S. Restrooms			5:12p	5:44p	2912			
	VQ 5886 L40C			5:20p	5:44p	2895			
	VQ 5928 L40D			5:36p	5:48p	2892			
	VQ 5900 FB			—	—	—			
	Ald-L40	Seppak		12:40p	7:22p	402	1.04	418	Aldehyde Scan TO-11
	Ald-FB			—	—	—	—	—	

CHAIN OF CUSTODY: Relinquished Marley Carroll MC Date 12/10/18 Received Date

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US Postal Service
Wisconsin Occupational Health Lab
PO Box 7996
Madison, WI 53707-7996

Phone 608 224-6210 800 446-0403 ***Sampling Questions*** WOHLsampling@mail.slh.wisc.edu
FAX 608 224-6213 ***Web Page/Order Media*** http://www.slh.wisc.edu/wohl

SAMPLE CONDITION
_____ OK
_____ NOT OK
See Sample Receipt Record

APPENDIX E: References

Azimi, Parham, et al. "Emissions of ultrafine particles and volatile organic compounds from commercially available desktop three-dimensional printers with multiple filaments." *Environmental science & technology* 50.3 (2016): 1260-1268. https://pubs.acs.org/doi/pdf/10.1021/acs.est.5b04983

Kim, Y.; Yoon, C.; Ham, S.; Park, J.; Kim, S.; Kwon, O.; Tsai, P.J. Emissions of Nanoparticles and Gaseous Material from 3D Printer Operation. Environ. Sci. Technol. 2015, 49, 12044−12053.

Oberdörster, G., et al. "Acute pulmonary effects of ultrafine particles in rats and mice." *Research report (Health Effects Institute)* 96 (2000): 5-74.

Donaldson, K. et al. "Nanotechnology." Editorial. Occupational and Environmental Medicine. 61(2004): 727-728.

NIOSH Health Hazard Assessment: HHE report No HETA-2017-0059-3291, Evaluation of 3-D Printer Emissions and Personal Exposures at a Manufacturing Workplace, https://www.cdc.gov/niosh/hhe/reports/pdfs/2017-0059-3291.pdf

Underwriters Laboratories: https://www.ul.com/newsroom/pressreleases/ul-chemical-safety-and-georgia-institute-of-technology-release-pioneering-3d-printing-research/

ASTDR Minimum Risk Levels: https://www.atsdr.cdc.gov/mrls/mrllist.asp

EPA Reference Concentrations: https://www.epa.gov/haps/health-effects-notebook-hazardous-air-pollutants

U.S. Occupational Safety and Health Administration, 29 CFR 1910 standards for air contaminants

American Conference of Governmental Industrial Hygienists, "2018 Guide to Occupational Exposure Values"

Also not cited in report:

https://www.canada.ca/en/health-canada/services/publications/healthy-living/residential-indoor-air-quality-guideline-acetaldehyde.html

https://www.canada.ca/en/health-canada/services/publications/healthy-living/residential-indoor-air-quality-guideline-formaldehyde.html

Appendix F: VOC Sample Locations

VOC Sample Locations
Samples Collected December 5 – 7, 2018

Sample ID/ Time Period	Location	Notes on 12/5/18
VQ5931/ 4:58 pm on 12/5/18 to 5:38 pm on 12/7/18	2nd Floor near spray booth	At 1101 Arch Core / Haber-Thomson, Warren Luke work space, adjacent to 3D MARS printer containing PLS white filament
VQ2855/ 5:12 pm on 12/5/18 to 5:44 pm on 12/7/18	Printer bank near 4-south restrooms	Attached to grated shelf, above "Grape" printer – PLA filaments observed in operating units
VQ5885/ 5:19 pm on 12/5/18 to 5:43 pm on 12/7/18	3rd floor - center	At 1221 UD Core/ Dou Jaiwei work area – three printers operating directly above on 4th floor
VQ5886/ 5:20 pm on 12/5/18 to 5:44 pm on 12/7/18	L40C	Office bench, work area adjacent to Stratasys objet260 Connex3™ and Stratasys BJET30 printers
VQ5928/ 5:36 pm on 12/5/18 to 5:48 pm on 12/7/18	L40D	Attached to exhaust duct, approximately 4 feet above floor level

Where direct-reading measurements were taken in similar locations (2nd, 3rd and 4th floors), instruments were placed within approximately 10 feet of the VOC sample. Otherwise, direct-reading instruments were placed in a general location within the room number indicated.