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NATIONAL STANDARD

ANSI/CAN/UL 2904:2023

STANDARD FOR SAFETY

Standard Method for Testing and
Assessing Particle and Chemical
Emissions from 3D Printers

SCC FOREWORD

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UL Standard for Safety for Standard Method for Testing and Assessing Particle and Chemical Emissions from 3D Printers, ANSI/CAN/UL 2904

Second Edition, Dated May 26, 2023

Summary of Topics

The Second Edition of ANSI/CAN/UL 2904 dated May 26, 2023 has been issued to reflect the latest ANSI and SCC approval dates, and to incorporate the proposals dated September 16, 2022 and February 24, 2023.

The new requirements are substantially in accordance with Proposal(s) on this subject dated September 16, 2022 and February 24, 2023.

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MAY 26, 2023

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ANSI/CAN/UL 2904:2023

**Standard Method for Testing and Assessing Particle and Chemical
Emissions from 3D Printers**

First Edition – January, 2019

Second Edition

May 26, 2023

This ANSI/CAN/UL Safety Standard consists of the Second Edition.

The most recent designation of ANSI/UL 2904 as an American National Standard (ANSI) occurred on May 26, 2023. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, Preface or SCC Foreword.

This standard has been designated as a National Standard of Canada (NSC) on May 26, 2023.

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Preface

This is the Second Edition of the ANSI/CAN/UL 2904, Standard Method for Testing and Assessing Particle and Chemical Emissions from 3D Printers.

ULSE is accredited by the American National Standards Institute (ANSI) and the Standards Council of Canada (SCC) as a Standards Development Organization (SDO).

This Standard has been developed in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization.

This ANSI/CAN/UL 2904 Standard is under continuous maintenance, whereby each revision is approved in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization. In the event that no revisions are issued for a period of four years from the date of publication, action to revise, reaffirm, or withdraw the standard shall be initiated.

Annexes [A](#) and [B](#) are identified as normative and form a mandatory part of this Standard.

Annexes [C](#), [D](#), [E](#), [F](#), [G](#), [H](#) and [I](#) are identified as informative and are for informational purposes only..

In Canada, there are two official languages, English and French. All safety warnings must be in French and English. Attention is drawn to the possibility that some Canadian authorities may require additional markings and/or installation instructions to be in both official languages.

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This Edition of the Standard has been formally approved by the Technical Committee (TC) on Chemical and Particle Emissions from 3D Printers, TC 2904.

This list represents the TC 2904 membership when the final text in this standard was balloted. Since that time, changes in the membership may have occurred.

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This Standard is intended to be used for conformity assessment.

The intended primary application of this standard is stated in its scope. It is important to note that it remains the responsibility of the user of the standard to judge its suitability for this particular application.

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INTRODUCTION

1 Scope

1.1 This standard presents methodologies for characterizing and quantifying coarse, fine, and ultrafine particles and volatile organic compound (VOC) emissions from operating three-dimensional (3D) printers under normal conditions of use in defined indoor environments including classroom, office, and residential scenarios.

1.2 This method primarily applies to the emissions of particles and volatile organic chemicals from 3D printers and feedstock which are widely used in classrooms, offices, libraries, residential settings, small and medium size enterprises, and other non-industrial indoor spaces. The 3D printers are operated with a variety of commercially available feedstock.

For environmental chamber tests under controlled conditions, a 3D printer's maximum size and format is limited.

For measurements, it is required that environmental chamber conditions are known and can be kept stable at least during the measurement.

1.3 The measurement protocols may be used to

- a) compare emissions from different feedstock or adhesion materials operated by a specific 3D printer, (material impact)
- b) compare emissions from printing objects of different shape, design, and size on a specific 3D printer (printed object impact)
- c) compare emissions from different 3D printers operated under identical conditions i.e. same object, same feedstock (print media), same environmental conditions (3D printer hardware impact)
- d) quantify emissions in a given specific exposure scenario – e.g. workshop, small production line, etc. (environmental impact)
- e) obtain data for use in risk assessments or product claims

1.4 This method includes requirements on laboratory quality management systems and measurement uncertainty estimation.

1.5 This standard establishes emissions criteria for particles and certain chemicals based on existing standards, guidelines, and research data for the management of airborne gaseous and aerosol pollutants in indoor environments.

1.6 This standard may be utilized as the basis for product testing and for certification/verification programs.

1.7 This standard specifies the maximum allowable concentrations of target chemicals and particles. However, this standard does not purport to address all of the safety, health, comfort (e.g., odor) and performance concerns, if any associated with its use. Users of this standard may establish additional safety, health, comfort and other performance conditions, and determine the applicability of regulatory requirements prior to use.

1.8 This standard provides guidance for use of the measurement protocols as a basis for product claims or verifications.

2 Undated References

Any undated reference to a code or standard appearing in the requirements of this Standard shall be interpreted as referring to the latest edition of that code or standard.

3 Definitions

3.1 Accumulated particle number concentration, $C_p(t)$ [cm^{-3}]

Time-dependent particle number concentration in a specified particle size range (at a minimum between 10 nm and 5 μm).

3.2 Aerosol

System of solid and/or liquid particles suspended in gas

[ISO 15900]

3.3 Aerosol measurement device

For the purposes of this test method, a device for determining the time-dependent particle number concentration of an aerosol within a defined particle size and concentration ranges and with a certain time resolution.

3.4 Air exchange rate (ACH), n [h^{-1}]

Ratio of the volume of clean air at room temperature (see [3.22](#)) and pressure brought into the chamber per hour [$\text{m}^3 \text{h}^{-1}$] to the unloaded chamber volume [m^3].

3.5 Air flow rate [$\text{m}^3 \text{h}^{-1}$]

Air volume at room temperature and pressure entering the environmental chamber per unit time.

3.6 Air velocity [m s^{-1}]

The air speed measured in the unloaded environmental testing chamber.

3.7 Aldehydes (ALD)

Aldehydes are low molecular weight organic compounds containing a functional group with the empirical formula, $-\text{CHO}$ and structural formula, $\text{HC}(=\text{O})$. The measured aldehydes are 2-butenal, acetaldehyde, benzaldehyde, 2,5-dimethylbenzaldehyde, 2-methylbenzaldehyde, 3 (and/or) 4-methylbenzaldehyde, butanal, 3-methylbutanal, formaldehyde, hexanal, pentanal, and propanal, individually calibrated to a traceable compound specific standard via High-Performance Liquid Chromatography (HPLC) analysis.

3.8 Average gas emission rate, $ER_{g,i}$ [$\mu\text{g h}^{-1}$]

Average mass of the analyte i (VOC or aldehyde) emitted from a tested 3D printer per unit time.

3.9 Average particle emission rate, ER_p [h^{-1}]

Average number of particles emitted from a tested 3D printer per unit print time, calculated from total number of emitted particles (TP) divided by the total print time in hours.

3.10 Blank value/ empty chamber background

Background concentration of the measuring system (environmental chamber, sampling media, and analyzer) for individual substances, total volatile organic compounds (TVOC) and particles including coarse, fine, and ultrafine particles.

3.11 Chamber loading

Placing a tested 3D printer into the environmental chamber.

3.12 Clean air

Air supplied to the chamber that meets requirements in [8.2](#) Chamber Parameters.

3.13 Coarse particles

Particles having an aerodynamic diameter greater than $2.5 \mu\text{m}$ and less than or equal to $10 \mu\text{m}$.

3.14 Condensation particle counter, CPC

Instrument that measures the particle number concentration of an aerosol by condensational growth to optical detection sizes using a working fluid such as water or butanol. For the measurement of total particle number concentration, a CPC with butanol as a working fluid is suggested.

3.15 Environmental chamber

An enclosed test environment consisting of a known volume with controlled environmental parameters used for the purpose of providing accurate and reproducible particle and chemical emission measurements from defined product sources.

3.16 Emission time [h]

Time between when 3D printer starts extruding (t_{start}) and 3D printer is no longer emitting new particles or 3D printer stops extruding, whichever comes after (t_{stop}).

3.17 Emission yield, EY_i [$\mu\text{g g}^{-1}$]

This quantity gives the mass of the analyte i (VOC or aldehyde) or the number of particles, which is emitted from a tested 3D printer per unit of mass of feedstock used.

3.18 Feedstock

3D printer media consumed to create a printed object, for example, filament and liquid resin.

3.19 Fine particles, FP

Particles having an aerodynamic diameter smaller than $2.5 \mu\text{m}$ and greater than $0.1 \mu\text{m}$.

3.20 Load factor

Quotient of the volume of the tested 3D printer (see [8.2](#)) and the volume of the empty environmental chamber.

3.21 Mass/number concentration

Mass/number of particles or mass of VOC per unit air volume at room temperature and atmospheric pressure.

3.22 Normal environment

Environmental conditions: 23 ± 1 °C, 50 ± 5 % relative humidity as per ISO 554. Conditioning environment is the same as normal environment.

3.23 Particles

Small discrete solid or liquid objects that can be chemically homogeneous or heterogeneous, and are suspended in air or gas with specified physical parameters.

3.24 Particle emission rate, $PER(t)$ [s^{-1}]

Time-dependent system-specific rate during the printing phase and post-operating phase.

3.25 Particle loss coefficient, β [s^{-1}]

Coefficient for describing particle loss in the environmental chamber.

3.26 Particle size/particle diameter

The physical dimension of a particle. The term particle size is often used as a synonym for particle diameter. The term particle diameter is also used to classify particles in particle size classes.

3.27 Particle size spectrometer based on electrical mobility

Instrument that measures the particle number concentration of an aerosol in various particle size ranges, where particle size is determined by particle electrical mobility.

3.28 Printing phase

Examination of the 3D printer during printing phase following pre-operating phase. The printing phase begins when the feedstock starts extruding and ends when the object is printed and the nozzle stops extruding and will not resume extruding.

3.29 Print time [h]

The length of the printing phase.

3.30 Pre-operating phase

Phase following the preparation phase. Experimental arrangement under normal environmental conditions where the 3D printer in the chamber is turned on (receiving electrical supply) and is waiting to start.

Warming-up and energy saving modes are included. At the beginning of the pre-operating phase the 3D printer is switched on. Thereafter the 3D printer is operated with the default settings for the feedstock used.

3.31 Preparation phase

First phase where the environmental chamber is prepared for testing. The phase includes chamber cleaning, unpacking test supplies, and confirming operability of 3D printer system.

3.32 Post-operating phase

Phase following the printing phase. Experimental arrangement in which the 3D printer is still in the chamber with the same air exchange rate as in the printing phase, but printing has already been completed.

3.33 Relative humidity, RH [%]

The amount of water vapor present in air expressed as a percentage of the amount needed for saturation at the same temperature.

3.34 Sampling interval

Time over which a single air sample is collected.

3.35 Sampling period

Established time for collection of an air sample from the environmental chamber.

3.36 Temperature, T [°C]

Degree of hotness or coldness expressed in degrees Celsius.

3.37 Test protocol

A defined process with specified materials, chemicals, application instructions and equipment for implementation in an environmental chamber.

3.38 Total volatile organic compounds, TVOC

The sum value of all compounds within the C₆ to C₁₆ range (those that elute between hexane and hexadecane) as measured by gas chromatography/mass spectrometry (GC/MS) techniques such as U.S. EPA Method TO-17 or ASTM D6196, and the concentrations of the converted areas of unidentified peaks using the toluene response factor.

3.39 Toluene equivalent

Concentration of an unidentified compound determined from Toluene calibration. For GC/MS analysis, the TIC (total ion chromatogram) shall be used.

3.40 Total particles, *TP* [-]

TP is calculated from the measured particle number concentration for a specified duration of particle emission sampling and quantifies the total number of emitted particles during a print job.

3.41 Ultrafine particles, UFP

Particles having an aerodynamic diameter less than or equal to 0.1 μm . UFPs have a diameter larger than nominally 7 nm or the minimum size that the aerosol measurement instrument can detect, which should be at least 10 nm.

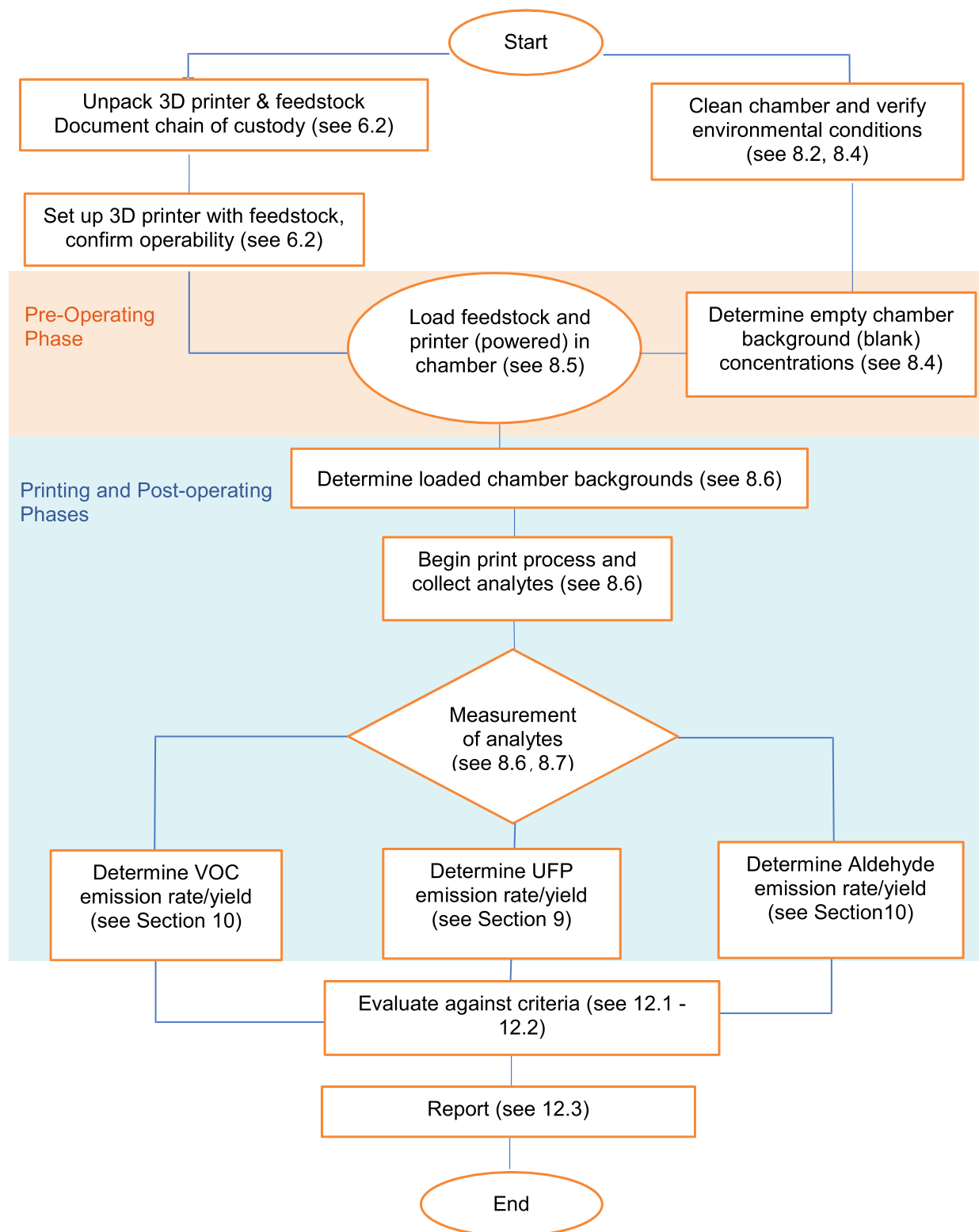
3.42 Volatile organic compounds, VOC

A VOC is any organic compound having an initial boiling point less than or equal to 250 °C (at minimum including n-hexane to n-hexadecane) measured at a standard atmospheric pressure of 101.3 kPa.

3.43 Very volatile organic compounds, VVOC

For the purposes of this test method, identified and unidentified organic compounds which elute from a gas chromatographic separation on a nonpolar column before n-hexane (e.g. ethanol, isopropanol, acetone, pentane).

4 Method Overview



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TEST METHOD AND ANALYSIS

5 Instruments for Environmental Condition Measurements

5.1 Environmental chamber

The chamber shall be constructed of stainless steel and non-adsorptive materials. Chambers shall have electropolished, or equivalent, interior surfaces to minimize wall loss. The chamber shall be designed and evaluated following ASTM D6670 guidance, UL 2823 (GREENGUARD Certification), ISO/IEC 28360, and ECMA-328. The chamber shall be designed as a single-pass system without recirculation of chamber air. The chamber shall be operated at a slightly positive pressure relative to the room to prevent the entrainment of room air. The chamber inlet and exhaust shall be positioned and designed to ensure complete mixing of chamber air. The chamber lid/door shall be non-contaminating, have a non-sorbing gasket and a closure mechanism to create an airtight seal. Other materials introduced into the chamber (e.g., racks and probes) shall be constructed of non-contaminating materials such as stainless steel. Tracer gas test procedure (ASTM E741 referenced through ASTM D6670) must also be performed on the chamber to ensure that the chamber air is well mixed with the supply air. The chamber is to be operated in accordance with [8.2](#).

5.2 Instruments for environmental measurement

For the test cycle and evaluation of the measurement results, the environmental data shall be recorded over the entire test procedure. For this purpose, a measuring system with an integral data logger is required. After performing the calibration, as a minimum, the following measurement accuracies shall be ensured:

- Temperature: ± 0.5 °C
- Relative humidity: ± 5.0 %

Electronic probes to measure temperature and relative humidity are to be placed inside the chamber or immediately at the chamber exhaust. The probes shall be calibrated periodically according to the laboratory's quality management system. At a minimum, these probes shall be calibrated on an annual basis against NIST traceable standards. Chamber inlet flow rates are also to be recorded weekly, as a minimum (and records are to be maintained).

5.3 Capillary gas chromatograph mass spectrometer with thermal desorption unit

The thermal desorber (TD) desorption and inlet parameters shall be optimized to obtain quantitative recovery of VOCs in the range defined in [8.6.2.1](#). The GC column and oven temperature parameters shall be optimized for the analysis of volatiles. The MS shall be an electron impact instrument operated in the scanning mode over a mass range of at least m/z 35 – 350.

The analytical methods for individual VOCs shall be based on ASTM D6196, ASTM D7339, and U.S. EPA Methods TO-17 and TO-1, or equivalent methods. Standards and chamber samples shall be analyzed using identical conditions.

5.4 High-performance liquid chromatography equipped with a UV detector

Formaldehyde, acetaldehyde, and other low molecular weight aldehydes samples shall be analyzed by HPLC equipped with a UV detector and an analytical column providing full resolution of the formaldehyde hydrazone derivative from unreacted 2,4-dinitrophenylhydrazine (DNPH) in a sample.

The analytical methods for formaldehyde, acetaldehyde, and other low molecular weight aldehydes shall be based on ASTM D5197 or an equivalent method. It is recognized that unsaturated low molecular weight aldehydes such as acrolein are not accurately determined by this method. Additionally, 2-butenal is subject to artifact effects (Ho et al., 2011).

5.5 Aerosol measurement instruments

A combination of aerosol measurement approaches is needed in order to capture (1) particle count for particle size ranging at minimum between 10 nm and 5 μm , (2) classification of particles by size, data correlation between the two (or more) aerosol instruments must be proven (an example shown in Annex [D](#), [D.4](#)).

A Condensation particle counter (CPCs) may be used as a stand-alone aerosol measurement instrument for total particle number concentrations. CPCs can be calibrated for their specific counting efficiency according to ISO 27891. A CPC should have at least 50 % detection efficiency for emitted particles greater than 10 nm in diameter, as specified by the CPC's particle detection efficiency (D_{50}) diameter. It should be recognized that the upper size detection limits of CPCs are not precisely specified and may be less than 5 μm (the upper limit of the recommended particle size spectroscopy range). Since the vast majority of particle in terms of numbers are in the fine and ultrafine range (i.e. have diameters less than 1 μm), variability in upper size limits among CPCs is not a significant issue. Particle contributions above 1 μm are considered negligible only for total particle number concentration measurements in this standard.

If the analysis of measured data indicates contributions of particle size fractions outside the instrument's size range to the emission, the aerosol instruments should be adapted accordingly. Such an indicator could be for example a cut-off of a particle size distribution at the upper size range of the instrument.

More details on aerosol measurement instruments and their readiness is in Annex [E](#), [E.2](#) and [G](#).

Example

Online particle measurements using three instruments: a CPC measuring total number of particles with diameter larger than nominally 7 nm to nominally 3 μm ; a particle size spectrometer based on electrical mobility measuring number distributions for particle electrical mobility diameter between 7 and 300 nm; and an optical particle counter (OPC) measuring particle number distributions for particle optical diameter of 300 nm to 25 μm . For CPCs, a typical lower particle number concentration detection limit is 0.01 cm^{-3} and a typical upper particle number concentration detection limit is 10^7 cm^{-3} . The minimum aerosol measurement time intervals vary from 0.1 seconds to 2 minutes.

5.6 Weight scale

The printed object shall be weighed at the end of each test. The scale shall be accurate to second decimal place of gram ($\pm 0.01 \text{ g}$).

6 Test 3D Printers

6.1 Print objects

6.1.1 Print object for single extrusion printers

The test print for a single extrusion 3D printer is to print a template file called 40mmcube.stl. (This template file can be downloaded at <https://www.thingiverse.com/thing:477>.) A cube object will be printed (see Annex [D](#), [D.3.1](#)). The print time may vary with different 3D printers, therefore the file (print size) is to be adjusted to print for 4 hours using normal/manufacture recommended 3D printer settings. The finished printed object shall weigh at least 25.0 g.

It is recommended to perform a rough calculation to predict the mass of finished product prior to the test using hardware and software parameters such as extrusion speed, density of the filament, filling percentage/density, and raft/skirt/brim options.

6.1.2 Print object for double extrusion printers

The test print for a double extrusion printer is to print a template file called Dual Material Test Print by dkschmidt. (This template can be downloaded at <https://www.thingiverse.com/thing:4768255>). An L-shaped object will be printed (see Annex D, D.3.2). The print time may vary with different 3D printers, therefore the file (print size) is to be adjusted to print for 4 hours using normal/manufacturer recommended 3D printer settings. The finished printed object shall weigh at least 25 g.

It is recommended to perform a rough calculation to predict the mass of finished product prior to the test using hardware and software parameters such as extrusion speed, density of the filament, filling percentage/density, and raft/skirt/brim options.

6.2 Preparation of the test 3D printer

The period of time between unpacking and preparation of the test 3D printer and feedstock shall be as short as practical, with exceptions reported. The time of placement of the test 3D printer in the conditioning environment shall be recorded.

NOTE: If printer is pre-loaded with filament, there may be a rise in concentration during the warm-up phase, this is to be included in calculations.

A test 3D printer shall be conditioned in clean air at controlled conditions of temperature and RH mentioned in 8.2, which are the same air conditions as inside the chamber, for a defined minimum period of 12 hours before initiating a printing test.

A 4-hour test run with the same conditions as for the coming test shall be made prior to placement of the test 3D printer in the chamber to ensure complete operability of the 3D printer and equipment.

For this purpose, a maximum of two 4-hour print cycles is permitted.

Printed parts and residuals left on the 3D printer shall be removed after each print job to ensure that there is no carry-over contamination. The cleaning instructions in the manual specific to the 3D printer should preferentially be followed, and feedstock residual shall be mechanically removed inside and outside of the extrusion piece. In fused filament fabrication (FFF), "Cold pull" (also known as "Atomic method") can be performed between changing the feedstock. It is a process where the feedstock inside the nozzle is melted, then cooled until nozzle temperature reaches around 100 to 140 °C for ABS and Nylon, 90 °C for PLA (temperature is dependent on filament material and is 3D printer specific), and the feedstock gets pulled from the top side to remove any blockage, dirt, and carbonized material out of the nozzle. If a nozzle can be taken apart, cleaning with acetone or ethyl acetate is also available, however these chemicals shall be fully evaporated before loading the 3D printer. If none of the above methods are successful, the nozzle shall be replaced. If the nozzle is replaced, the new nozzle shall be cleaned before use. The nozzle cleaning procedure or a nozzle replacement shall be reported.

Placement of a test 3D printer in the conditioning environment establishes the beginning of the test period. This critical time shall be recorded and all subsequent times for transfer of the specimen to the test chamber and collection of air samples from the chamber shall be scheduled relative to this initial time. A ± 2 % deviation in transfer time and sampling times is allowed. Control and monitoring of the 3D printer and the printing process in the sealed environmental chamber is to be established and controlled from outside.

A 3D printer shall be tested with a configuration that allows a 4 hour printing time extruding feedstock from one or more nozzles. Additional tests are suggested for a 3D printer with multiple extruder nozzles, i.e., separate tests using one extruder nozzle each time with all the other settings the same. If applicable, recommended add-ons (such as devices to condition the feedstock), platform adhesives, or surface preparation should be applied prior to loading in an environmental chamber.

The 3D printer shall be tested with the default setting (standard print quality) to print in a manner a user is most likely/advised to print unless advised otherwise by the customer. Print settings are to be recorded and clearly identified in the report. Each 3D printer with any variation in the parameters listed above shall be tested separately.

6.3 Feedstock

The testing laboratory shall be provided with the exact name, manufacture, color of the feedstock, For each device, the feedstock in the device shall be as specified in the manufacture's instruction manual or website. The testing laboratory shall be provided with the exact name, manufacture, color of the feedstock, diameter, lot number or another form of traceability, such as spool identification number, the minimum, maximum, and recommended print settings and nozzle temperatures, and recommended extrusion speed for that feedstock. A current Safety data sheet (SDS), CAS number(s), the country of origin of main polymer additives/dyes should be provided. Each feedstock with any variation in the parameters listed above shall be tested separately. If applicable, recommended platform temperature and adhesives or surface preparation should be provided. In any case, reserve samples are highly recommended.

Examples of typical feedstock include, but are not limited to, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), thermoplastic polyurethane (TPU), nylon, and polycarbonate.

The feedstock shall be stored according to the manufacturer's instructions until the test, and the feedstock shall be provided in sufficient quantities.

NOTE: During storage, chemical contamination should be avoided.

7 Quality Assurance Measures

Quality assurance when applying the test procedure is a necessary prerequisite for obtaining reliable emission data. ECMA-328 and ISO/IEC 28360 give an overview of this topic.

8 Environmental Chamber Testing and Analyses

8.1 Measured variables

- Particle count as a function of particle size
- Total particle count within a defined size range (minimum required size range is 10 nm to 5 µm)
- Individual VOC concentration
- Individual aldehyde concentration
- Total VOC concentration

8.2 Chamber parameters

Depending on the volume of the 3D printer to be studied, a chamber with the appropriate volume shall be selected (see Equation 1). The volume of a 3D printer is defined as the multiplication of the projected area

and height of the 3D printer during a regular function with enclosure doors closed and not including unattached material feedstock if there are any. The chamber size needed for the test 3D printer is selected based on the criterion for the load factor in Equation 1:

$$0.01 < \frac{V_{3D \text{ printer}}}{V_C} < 0.25 \quad (1)$$

where $V_{3D \text{ printer}}$ is the volume of the 3D printer (m^3) and V_C is the volume of the empty test chamber (m^3). The smallest possible chamber shall be used by the testing institute since the volume dependent measured concentrations are greater and thus the uncertainty is reduced. During the test, only one 3D printer is to be in the environmental chamber. The chamber shall not be opened, and no people shall stay in it. When a fault (e.g. feedstock jam or print object not shaping, etc.) occurs, the test shall be repeated.

Test chambers shall have sufficient sealable bushings through the wall for passing power and control cables and allow the simultaneous sampling of VOCs and particles. Recommended test chamber conditions are listed below. Drier air may be required for extruding materials if they are susceptible to moisture (e.g., RH < 5 %). RH used shall be reported.

- Temperature: 23 ± 1 °C
- Relative humidity: 50 ± 5 %
- Adjustable air exchange rate (in h^{-1})
 - Large chamber ($V_C > 5 \text{ m}^3$): $(1 < n < 2) \pm 5$ %
 - Small chamber ($V_C < 5 \text{ m}^3$): $(1 < n < 5) \pm 5$ %
- Air velocity: $0.1 - 0.3 \text{ m s}^{-1}$ surface velocity is recommended

There shall be no condensation of water in the chamber as this would lead to an undue influence on the measurement results.

Chambers are to be regarded as suitable if, in addition to compliance with the above conditions, they have sufficiently low empty chamber background values for VOCs and particles.

Before the chambers are first used, and repeatedly thereafter, they shall be cleaned and checked for compliance with the requirements. The empty chamber background values at an air exchange rate of $n = 1 \text{ h}^{-1}$ are to be less than the following values:

- Individual substances: $2 \mu\text{g m}^{-3}$
- TVOC: $10 \mu\text{g m}^{-3}$
- Total particle count concentration: 2000 cm^{-3} (e.g., CPC)
- Total particle mass concentration: $1 \mu\text{g m}^{-3}$ (e.g., particle size spectrometer and OPC)

The empty chamber background value for FP/UFP shall be checked by a sufficiently sensitive instrument (usually a CPC and/or particle size spectrometer).

The air exchange rates needed for the measurement shall be regularly checked and documented using an independent method, e.g. tracer gas method according to ASTM E741 for tracer gas application for an unloaded state.