

## Introduction

3D printers at MIT are increasingly used to print concept models, functional prototypes, replacement parts and fixtures for research and student projects. 3D printing, also known as additive manufacturing, is a type of digital fabrication where objects are built from digital models by depositing material in successive layers. Unlike traditional machining—which is a subtractive process that shapes an object by cutting, grinding, or milling away material—3D printing builds objects by adding material only where it is needed.

There are several 3D printing technologies available<sup>1,2,3</sup>; they are differentiated by the means of material deposition. The infrastructure and safety requirements can vary widely depending on these technologies. Before purchasing a printer, a thorough understanding of the printer operational needs and whether the available space can accommodate them is important.

While the hazards of traditional machining are well studied, additive manufacturing has its own potential hazards that are often not as well recognized by both manufacturers and users. This guidance provides recommendations helpful in recognizing and controlling 3D printing hazards.

## Common Considerations for All 3D Printers

Common EHS concerns for 3D printers include:

- **Ventilation**—Effective general exhaust ventilation is recommended for all 3D printers. The exhaust should be ducted directly to the outside and not recirculated as is a common practice in non-lab spaces. Certain printing technologies have additional local exhaust requirements.
- **Chemical Safety**—Users should read and understand the Safety Data Sheets (SDS) for both the printing materials and any chemicals used in part finishing. In assessing chemical safety, consideration should also be given to airborne emissions from the printing process such as nanoparticles and organic vapors. If the end use of your printed part includes contact with chemicals, ensure the printed part material is compatible with the chemical(s) used. Don't substitute generic 3D printer consumables for manufacturer approved products. Ensure that chemical containers are labeled.

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<sup>1</sup> ISO/ASTM 52900:2015(E) *Standard terminology for additive manufacturing technologies –general principles - terminology*; 2015.

<sup>2</sup> Dobrzyńska, *et al*, State of the art in additive manufacturing and its possible chemical and particle hazards—review. *Indoor Air*. 2021;00:1–26.

<sup>3</sup> UL 200B - Safe Use of 3D Printing for Institutions of Higher Education.

# EHS Considerations for 3D Printing

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- **Parts Finishing Requirements**—Printed parts require varying amounts of finish work. A separate work area and equipment for post processing that may include tasks such as sanding, polishing, and curing is required for some printing technologies. A bath with flammable or caustic liquids for cleaning residues or removing print support structures may be needed.
- **Location**—Due to the considerations listed above, 3D printers should not be in office spaces, dorm rooms and other residences. Printers should be placed on a stable nonflammable surface away from combustible materials. 3D printers located in a shop or makerspace should be segregated from tools and equipment that produce dust or sparks. If flammable or caustic materials are used, the room should be equipped with an eyewash station, and a lab sink and it should be confirmed that there is a fire extinguisher nearby.
- **Printer or process modification**—If you are modifying/building a 3D printer or using a novel material, work with EHS to ensure you are not introducing new safety concerns.
- **Training**— All users need training on potential hazards and safe operation. This training should be specific to their 3D printer (type and manufacturer). Sources of information to develop training include this guide, equipment manuals, the manufacturer website and other best practices.
- **Hazardous Waste** – Waste determination should be performed on all chemicals used in fabrication and post processing prior to disposal. Contact [EHS](#) if you have questions about new waste streams.
- **Personal Protective Equipment (PPE)** – PPE, especially eye protection, is often required for safe operation of 3D printers. Safety glasses are recommended, particularly during post-processing, to protect your eyes from resin, dusts, support fragments, or other debris. Nitrile gloves should be used when handling resins.
- 3D printer owners should also read and adhere to the safety guidance for their equipment in the manufacturer’s equipment manual and website. Don’t use your printer for personal health products unless the print material is designed for that purpose and you have appropriate permissions.
- 3D printers should be listed by a [Nationally Recognized Testing Lab](#) (NRTL) when possible.
- In addition to NRTL listing, 3D printer purchasers should look for printers that certified for product safety compliance with appropriate safety standards and regulations<sup>4</sup> such as UL 60950 and UL 62368-1. Consider selecting printers that meet ANSI/CAN/UL 2904 Standard criteria for particle and chemical emissions.
- Contact your EHS Coordinator or the [EHS Office](#) with any additional questions.

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<sup>4</sup>[https://code-authorities.ul.com/wp-content/themes/countries/downloads/am/3D-PRINTING-EQUIP-SAFETY-GUIDELINE\\_EDITION2.pdf](https://code-authorities.ul.com/wp-content/themes/countries/downloads/am/3D-PRINTING-EQUIP-SAFETY-GUIDELINE_EDITION2.pdf)

## Fused Deposition Modeling (FDM)

By far the most common 3D printing technology at MIT and other academic institutions is Fused Deposition Modeling (FDM), sometimes called Fused Filament Fabrication (FFF). The small desktop printers in many shops and makerspaces are usually FDM. With this technology, a heated thermoplastic filament is extruded through a temperature-controlled print head in a semi-liquid state to build a part layer by layer. Although there are some larger industrial FDM printers at MIT, most are suitable for prototyping smaller objects. PLA (Polylactic Acid) and ABS (Acrylonitrile Butadiene Styrene) are the most common materials used in FDM printers, but many other materials are available.

Desktop FDM Printer (courtesy of Prusa)



Large Format FDM Printer



## EHS Concerns and Controls for FDM Printers:

- Ultrafine Particles (UFP) and Volatile Organic Compounds (VOC)—Studies of FDM printer emissions have shown that UFPs and VOCs are generated during the printing process<sup>5</sup>. While the health effects from these emissions are still being studied, limiting personal exposures, especially if you have multiple printers and/or they run often is prudent. Of the two most common materials used with

<sup>5</sup> Min *et al* 3D Printing-Induced Fine Particle and Volatile Organic Compound Emission: An Emerging Health Risk *Environ. Sci. Technol. Lett.* 2021, 8, 8, 616–625 Publication Date: June 28, 2021  
<https://doi.org/10.1021/acs.estlett.1c00311>

FDM printers, Acrylonitrile butadiene styrene (ABS) filament was shown to produce more VOCs and UFPs than Polylactic acid (PLA).

- Ventilation—The ventilation strategies used to control air contaminants are applicable to 3D printers<sup>6</sup>. Directly exhausting an enclosed printer is more effective in reducing emissions than general exhaust.
  - General Ventilation: When general exhaust ventilation is used as part of a control strategy for FDM 3D printer emissions, the exhaust should be non-recirculating exhaust to the outside (NIOSH guidance recommends a minimum 2 to 4 ACH in larger makerspaces, in a smaller room, e.g., 10 ft<sup>2</sup> x 10 ft<sup>2</sup>, design for 6 ACH)<sup>7</sup>. Locate the 3D printing area to take advantage of room airflow patterns to provide a more effective general exhaust for UFPs and VOCs. In some cases where room air changes are insufficient, EHS may recommend portable HEPA filter units to increase effective air change rates.
  - Isolation: Purchasing a printer with an enclosure or buying an aftermarket enclosure will cut down on emissions and may improve print quality.
  - Local Exhaust: Venting the enclosure into a lab exhaust system or a well-designed filtration system that captures both UFPs and VOCs will effectively reduce the concentration of these contaminants. A canopy hood over the 3D printer will capture some contaminants but will not be as effective as an exhausted enclosure.
  - When considering an exhaust strategy for printer clusters of 3 or more, local exhaust options such as enclosed, ventilated racks<sup>7</sup> should be considered.
- Alkaline baths and hazardous waste—Some 3D printers print temporary support structures. The support material can be removed by soaking the part in a heated bath with a caustic solution. These baths must be set up in a suitable location with input from EHS. The spent bath solution needs to be collected as hazardous waste by EHS. Ensure the bath is labeled with the chemical and hazards.
- Water soluble PVA—Supports can also be removed using water soluble PVA. The spent solution should be collected as waste.
- Water baths or pressure washing stations to remove supports or excess materials from non-soluble supports, should have all solids filtered prior to discharge.

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<sup>6</sup> Viitanen, et al Technical Control of Nanoparticle Emissions from Desktop 3D Printing. Indoor Air. 2021;31:1061–1071

<sup>7</sup> NIOSH [2023]. Approaches to safe 3D printing: a guide for makerspace users, schools, libraries, and small businesses. By Hodson L, Dunn KL, Dunn KH, Glassford E, Hammond D, Roth G. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 2024-103, <https://doi.org/10.26616/NIOSH-PUB2024103>

- Hot Surfaces—Since the print head can be heated to temperatures over 200°C, accidentally contacting these surfaces can cause burns. Awareness training for users is important. Consider using an enclosure and signage to help prevent accidental contact and include a step in the user instructions to let the printer cool before opening the enclosure.
- Pinch points—There is a potential for a hand injury from an unguarded print assembly if you reach inside the printer during operation. Awareness training is important; an enclosure will also make this less likely.
- Cut hazards—Removing the model from the print bed with a scrapper or finishing of printed objects with hand tools can result in serious cuts. Users should be trained in good hand tool safety practices. A removable print surface or a printer with a flexible build plate should be considered to minimize scrapper use. EHS has a separate [guidance](#) on safely removing parts from build plates
- PPE —Always wear safety glasses and consider cut resistant gloves when removing support material by hand. The support material can be brittle and may cause cuts if manually broken off.
- Fire Risk —The print head may overheat if the temperature control fails. Purchase FDM printers with thermal runaway control and ensure that this protection is enabled. Keep areas around 3D printers clear of combustible and flammable materials.
- Waste disposal — Waste determination should be performed on all chemicals used and support materials prior to disposal.

## Note on Ultrafine Particles (UFP) and Volatile Organic Compounds (VOC)

Ultrafine Particles (UFP): UFPs are defined as particles with a diameter of less than 0.1 micron. The rate of UFP emissions is dependent on the type of filament used. PLA filaments, which melt at a lower temperature, typically have the lowest emission rate of all filaments. ABS and nylon filaments tend to have higher emission rates.

Volatile Organic Compounds (VOC): The process of melting thermoplastics, as is done in FDM printing, emits VOCs. Types and concentration of VOCs emitted depend on the type of filament used and any additives.

## Stereolithography (SLA)

Stereolithography (SLA) is a type of vat photopolymerization, that is, it involves a vat or bath of liquid photopolymer resin. SLA uses a UV laser to trace a cross-section of the part pattern on the surface of the liquid resin. The ultraviolet laser light solidifies the pattern traced on the resin and joins it to the layer below. An elevation mechanism

lowers the part at the completion of each layer. There are a variety of photopolymers with different chemical compositions that may be used. Therefore, a location both with adequate general or local exhaust ventilation and suitable for chemical handling is required.

## EHS Concerns and Controls for SLAs:

- Resin handling—Be aware that there may be unreacted resin on the part and build plate. Many resins can cause skin sensitization after repeated exposure so good handling procedures and housekeeping is essential. External guidance for handling resins can be downloaded [here](#).
- There are a variety of photopolymers with different chemical compositions that may be used. Careful review of SDSs, especially for new resins, is important.
- 3D printers have built-in safety features that are designed to prevent an operator exposure to uncured photopolymers and UV laser light – do not try to change or disable these features.
- Flammable liquids—Residual resin is cleaned from SLA printed parts in a bath with isopropyl alcohol (IPA) or other solvent. The bath should be in a well-ventilated room away from combustible materials. Ensure the bath has proper chemical labeling. Containers of IPA should be properly stored. Note that the baths for larger format printers can contain 5 gallons of IPA which may increase concerns for chemical storage and exceeding flammable liquid limits.



Alcohol bath to remove resin from a SLA Printer

- UV light—Parts may be cured in a UV oven. Do not modify the oven or printer enclosure to defeat any safety features and interlocks that protect against UV exposure.

- Waste disposal— Waste determination should be performed on all chemicals used and support materials prior to disposal. Uncured resins must be disposed of as hazardous waste.

## Material Jetting/Polyjet

Polyjet is a patented name while material jetting is the technical name for the process are the same technology. Polyjetting uses a print head to jet liquid photopolymers onto a build tray where each droplet cures under ultraviolet light. The photopolymers used are similar to those used in SLA. Multiple polymers can be used in a single build. The EHS concerns associated with material jetting are similar to SLA printers.

- Resin handling—General guidance for handling resins can be downloaded [here](#).
- Careful review of SDS's especially for new products is important.
- 3D printers have built-in safety features that are designed to prevent an operator exposure to uncured photopolymers and UV wavelengths – do not try to change or disable these features.
- Flammable liquid—SLA printed parts are cleaned of excess resin in an isopropyl alcohol bath.
- Waste disposal— Waste determination should be performed on all chemicals used and support materials prior to disposal. Uncured resins must be disposed of as hazardous waste, and the isopropyl alcohol used for cleaning is also collected as hazardous waste.
- Polyjet printers may have ventilation requirements that include a hazardous exhaust connection.

## Selective Laser Sintering (SLS)

SLS involves the use of a high-power laser to selectively fuse fine polymer powder by tracing cross-sections generated from a 3D digital description of the part (for example from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the selective laser sintering process is repeated until the part is completed. EHS concerns include:

- Ensuring selected location is appropriate with good general exhaust ventilation.
- Class 4 laser for sintering (reclassified to Class 1).
- Handling and storage of powders to prevent combustible dust hazards
- Users should receive detailed training on equipment operation, understand the potential hazards with combustible materials and know to only use a Class II, Div II vacuum for powder clean-up.

- Waste disposal— Waste determination should be performed on all used powder prior to disposal.

## Direct Metal Laser Sintering (DMLS)

With Direct Metal Laser Sintering (DMLS), a technology related to SLS, a roller spreads a thin layer of heated metal powder material in a print bed, and a laser fuses (sinters) the powder into a solid form(s) in the desired cross-sectional shape. This 3D printing technology has significant infrastructure requirements and needs a dedicated space designed for the 3D printer and specialized equipment for parts finishing and powder mixing. DMLS printers may use a variety of metals. EHS concerns include:

- Ensuring appropriately designed location with good general exhaust.
- Location should comply with fire and building code requirements for combustible dust
- Handling and storage of powders to prevent combustible dust hazards.
- Cryogenic materials for inert atmosphere in print chamber (oxygen depletion hazard)
- Development of SOPs and training of users
- Hazards during maintenance tasks
- Class 4 laser for sintering (reclassified to Class 1).
- Waste disposal— Waste determination should be performed on all used metals and any other materials prior to disposal. Depending on the specific metals used, and the particle size, waste metal powders and contaminated filters sometimes meet the definition of hazardous waste. Contact EHS for assistance.

## Bound Metal Deposition (BMD)

BMD is like FDM in that it is an extrusion-based process. With BDM, metal components are created by the extrusion of a powder-filled thermoplastic media held together by both wax and polymer binder. The media along with support material is heated and extruded onto the build plate layer by layer. Less infrastructure is required for BMD than DMSL printers because the metal powders are not free flowing and do not present a combustible dust hazard. A debinding machine and a furnace are required for finishing. EHS concerns include:

- Suitable shop or lab space with general exhaust ventilation.
- Waste disposal— Waste determination should be performed on all chemicals used and support materials prior to disposal. Depending on the specific metals used, and the particle size, waste metal powders and contaminated filters sometimes meet the definition of hazardous waste. Contact EHS for assistance.

# EHS Considerations for 3D Printing

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## Summary Table

Technology	Description	Common Materials	Hazards	Ventilation Controls
<b>Fused Deposition Modeling (FDM)</b>	Objects are constructed by laying heated thermoplastic filaments from the bottom up	Thermoplastics (e.g. PLA, ABS),	Nanoparticles and VOCs from extrusion, caustic solution in parts bath, cut hazards during finishing	Effective general exhaust ventilation. Desktop models may be enclosed and vented either into an exhaust or filtration system.
<b>Vat Polymerization/ Stereolithography (SLA)</b>	Selectively hardens light-sensitive liquid resin layer-by-layer forming a 3D model from bottom-up	Photopolymer Resins	UV light (SLA), VOCs from bath, Uncured resin	Effective general exhaust ventilation may be acceptable but local exhaust is preferred
<b>Material Jetting/Polyjet</b>	Similar to a standard inkjet printer except multiple layers are built upon each other to create a solid part. Each layer is cured/solidified them using an ultraviolet (UV) light.	Photopolymer Resins	Uncured resin	Connection to hazardous exhaust system required for most printers
<b>Selective Laser Sintering (SLS)</b>	Uses a high-power laser beam to sinter powdered materials to create 3D objects	Plastic	Class 4 laser, reactive and combustible powders, cryogenics,	Effective general ventilation from a hazardous exhaust system
<b>Direct Metal Laser Sintering (DMLS)</b>	Uses a high-power laser beam to sinter powdered materials to create 3D objects	Metal powders Aluminum, stainless steel and other alloys	Class 4 laser, reactive and combustible powders, cryogenics,	Effective general ventilation from a hazardous exhaust system
<b>Bound Metal Deposition (BMD)</b>	is an extrusion-based metal additive manufacturing (AM) process where metal components are created by extrusion of a powder-filled thermoplastic media	Stainless steel, nickel alloy, copper		Good general exhaust ventilation