Stanford | Environmental Health & Safety
Research Safety

3D Printing Safety and Health Guidance

Additive Manufacturing (AM) is commonly known as 3D printing, which is the process of creating an object by building up successive layers of material based on a 3D digital file. 3D printing allows for rapid prototyping and small-scale manufacturing, which is well-suited to the fast-paced needs of research and teaching. However, there are hazards associated with 3D printing. This guidance document outlines the hazards associated with 3D printing and the methods to minimize risk. Principal Investigators/Laboratory Supervisors/3D printer owners are expected to implement all feasible safety measures.

Hazards

The hazards associated with 3D printing depend on the type of printer, materials used, and processes and techniques. Briefly, 3D printers can expose users to Volatile Organic Compounds (VOCs) and ultrafine particles (UFPs), which vary greatly based on the material used, print method, and print temperature. Post-processing steps can also expose users to flammable or corrosive chemicals or cuts due to handling sharp objects.

Minimum Safety Measures

1. Printer must be listed by an NRTL.
2. Avoid using 3D printers in poorly-ventilated environments like offices, libraries, and residence halls.
3. 3D printers should be used in spaces with > 4 ACH.
4. Use of materials other than PLA should be in spaces with > 6 ACH.
5. Banks of > 3 printers that can run simultaneously should be in labs with >6 ACH, once through air.

General Health Hazard Risk Assessment

Based on published academic and occupational research, levels of individual volatile organic chemicals are expected to be in the parts-per-billion range, which is well below applicable Occupational Exposure Limits, such as Cal/OSHA Permissible Exposure Limits (PEL). Levels of particulate matter are also expected to be well below the applicable Cal/OSHA PEL. It should be noted that there are no applicable exposure limits specific to ultrafine particles generated from 3D printers. Given that research into health effects and appropriate exposure limits is on-going, EH&S recommends minimizing exposure to VOCs and UFPs from 3D printers by implementing the safety measures discussed below.

Safety Measures

The following safety measures are important controls to minimize the risk of working with 3D printers.

Selection

- Printers must be listed by a Nationally Recognized Testing Laboratory (NRTL), which is required by workplace electrical safety standards and fire code. Refer to this list of NRTLs when evaluating printers. Please note that CE is *not* an NRTL.
- Choose printers and feedstocks that meet the ANSI/CAN/UL 2904 Standard (look for UL 2904 or GREENGUARD certification), which sets maximum allowable emission rates for VOCs and total particles.
- Use PLA (polylactic acid) filaments whenever feasible, which have been shown to have lower VOC and particle emissions than ABS and nylon.
- Use the filament type and brand recommended by the printer manufacturer.
- For printers that use lasers or non-ionizing radiation, only purchase those that are interlocked to turn off the laser or non-ionizing radiation source when the cover is opened.

Ventilation

- Dedicated exhaust is always a preferred method to remove airborne contaminants. Examples include:
    - An enclosure that is exhausted outdoors (e.g., uses laboratory ventilation and ducting).
    - A chemical fume hood.
    - A custom print-head capture hood, as described in a NIOSH guidance document.
    - A snorkel truck that is designed to ACGIH standards (Lab Design Guide, Section 3.3 #10).
    - Following EHS review, a canopy hood may be acceptable.
    - If there are operable windows, there are also kits that exhaust 3D printer enclosures to the outside via a window. For small operations (1-2 printers), opening a window near the printer(s) will also reduce air contaminants.
- Location
    - Printers should be used in well-ventilated environments with at least 4 air changes per hour (ACH).
    - Banks of >3 printers that can run simultaneously should be in rooms with at least 6 ACH, once-through air, which is typical for laboratories. Where that is not feasible, consult with EHS.
    - Avoid using 3D printers in poorly-ventilated environments like offices, libraries, and residence halls.
    - Use higher-temperature filaments (i.e., anything other than PLA) only in well-ventilated environments with at least 6 ACH.

Work practices

- Use the printers according to the manufacturer's instructions.
- Select the lowest feasible/recommended temperature for printing, which minimizes VOC and UFP emissions.
- Use any corrosive wash solutions in locations with an eyewash and safety shower.
- Have an appropriate fire extinguisher available where 3D printers are used.
- Review the Safety Data Sheet (SDS) for any print materials to familiarize yourself with the hazards.

Personal Protective Equipment (PPE)

Eyewear

- Wear safety glasses or safety goggles whenever loading or unloading a printer, doing post-processing, cleaning, or handling uncured resin. Prescription glasses do not offer the same protection as safety glasses or goggles.
- If unguarded lasers are used in the printer, consult the manufacturer's guidance for appropriate laser safety eyewear.

Body protection

- Wear a lab coat when handling uncured resin or wash solutions.
- Wear appropriate street attire at all times, long pants (or equivalent), shoes that cover the entire foot, tie back long hair, and remove dangling jewelry.

Respiratory Protection

- In general, use of 3D printers does not require a respirator. If you would like to use one, reach out to EHS for an assessment.
    - Note that nuisance dust masks will not reduce exposure to VOCs or UFPs and they are not NIOSH-approved.

- N95 respirators can reduce exposure to UFP, but not VOCs. If 3D printer users elect to use an N95 respirator for UFP protection for comfort purposes during the 3D printing operation, in accordance with the Cal/OSHA Title 8 CCR 5144 Respiratory Protection Standard and the University Respiratory Protection Program, , N95 users need to review and sign N95 Voluntary Respirator Use Guidance, then submit a copy of the completed agreement to their supervisor. PIs and supervisors should retain the record as long as the users use the respirator.
- EHS has assessed metal printing using stainless steel and determined that respirators are not required. However, if other metals are used or any metal powders are sieved, they will need to be assessed for respiratory protection needs. Please contact EH&S for a respirator assessment of metal 3D printing.

Gloves

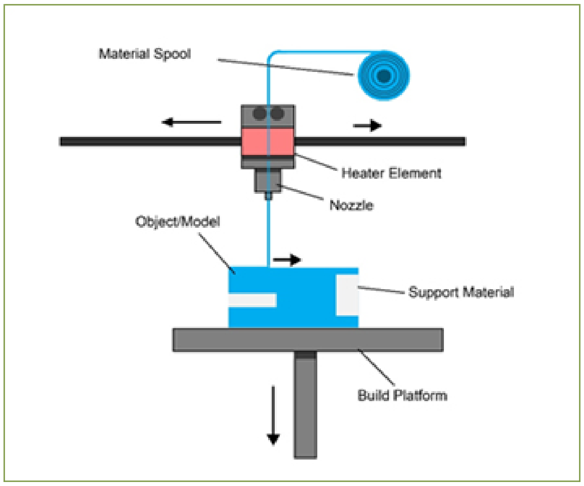
- Wear disposable nitrile gloves when handling uncured resin, supports, and wash solutions except for corrosives or toxic chemicals that readily penetrate skin.
  - Read the SDS to determine the appropriate glove for corrosives for toxic chemicals that readily penetrate skin.
- Wear cut-resistant gloves when using tools or razors to remove supports or remove an object from the build plate.
- Clean build plates and print heads regularly to minimize fire risk.

3D Printing Methods Summary

Several 3D printing methods are presented within this section and associated with each method is the process, feedstock materials, form of the feedstock, e.g., powder or liquid resin and potential hazards. Feedstock materials and the equipment used in the process can generate health hazards. To aid in understanding each 3D printing method, a figure is provided.

Material Extrusion

Material extrusion, also referred to as fused deposition modeling, uses a nozzle to move two-dimensionally to deposit a layer of material onto a build platform. This platform is lowered or the nozzle is raised to permit deposition of subsequent layers. See figure below

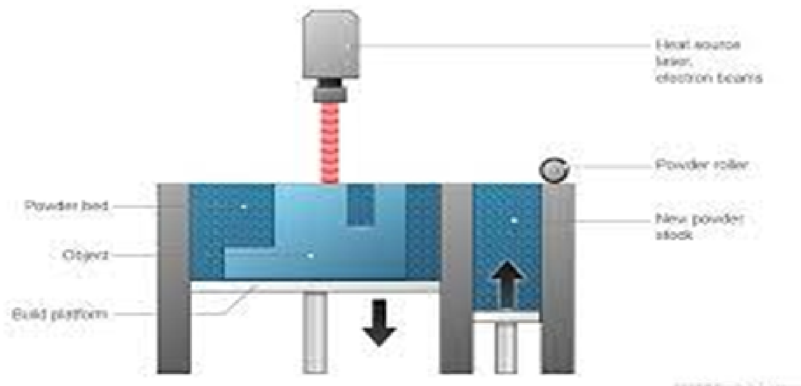


Most common materials used in this process are thermoplastics such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polycarbonate (PC) and polyamide (nylon). These materials are in the form of a filament that is melted by a heated nozzle. Filaments may also include ceramic or metallic particles.

This process may release volatile organic compounds (VOCs) such as styrene and particulate matter exposing staff and students to health hazards. The particulates may be present as ultra-fine nanoscale particles (less than 100 nanometers in diameter) capable of being inhaled deeply within the lungs. Other hazards associated with this process are contact with hot surfaces and physical hazards related to sanding, grinding and polishing.

Powder Bed Fusion

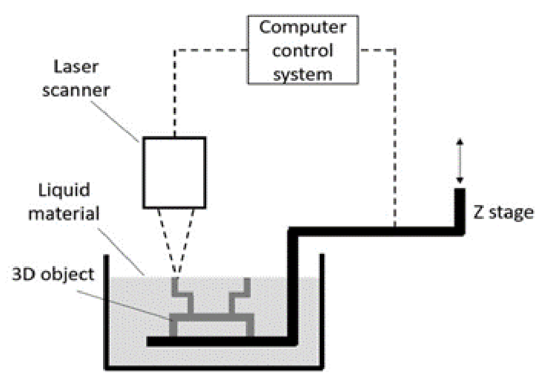
Powder bed fusion or selective laser sintering begins with a build platform covered in a layer of powdered material, which is fused by a heat source (laser). The platform is lowered and another layer of powder deposited forming a shape of an object. A figure on the next page illustrates this process.



Feedstock materials used in this process are metals, ceramics or plastics. Examples of these materials are silicon carbide and aluminum and these materials are present in the form of a powder. Fine powder may create inhalation and dermal exposures. Additionally, this powder may be a source of fire and potential explosion. Handling of metal powders requires grounding measures such as antistatic wrist straps and grounding of the equipment. Exposure to a laser or electron beam should be avoided as a laser may damage the eye and an electron beam produces ionizing radiation.

Stereolithography/Vat Photopolymerization

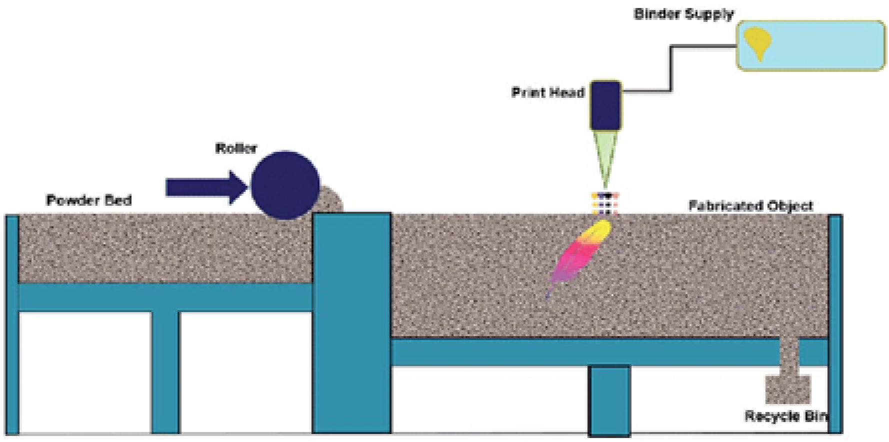
Stereolithography or vat photopolymerization involves depositing layers of liquid photopolymer resin to create an object. Each layer is cured using an ultraviolet (UV) laser or digital processing lamp. This process is shown below.



The photopolymer resin used in this process may consist of acrylates or epoxides. Heating this resin may emit VOCs causing inhalation and dermal exposures. Caution should be used during operation of the laser.

Binder Jetting

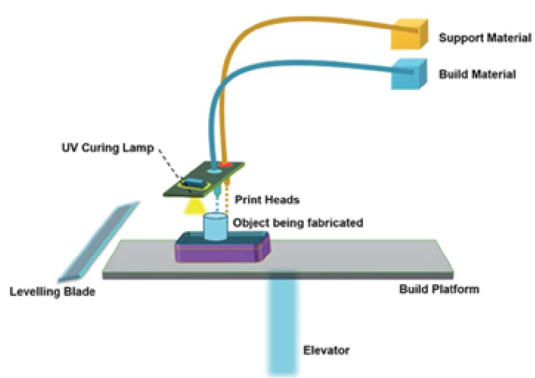
Binder jetting or drop-on-powder printing begins with a build platform covered in a layer of powder. The powder is deposited in layers to create an object. An adhesive is applied by a print head to bond the layers of powder. The process is depicted below.



Potential powder used during this process can be a metal, ceramic or plastic. An example of this powder is calcium carbonate or acrylate. As in powder bed fusion, inhalation and dermal exposures may occur during this process as well as explosion hazards. Use of adhesives may create a flammable hazard.

Material Jetting

Material jetting involves using a print head to deposit a photopolymer resin on a build platform. Several layers of the resin are placed forming an object. This resin is cured and solidified using UV light. Figure provided below illustrates this process.



This process shares many of the hazards associated with stereolithography since it uses a photopolymer resin and many of the same operations. Additionally, curing agents such as cyanoacrylates can create hazardous vapors.

Bioprinting

Bioprinting is the deposition of biological molecules, materials and organisms. This process incorporates several techniques already discussed such as material extrusion and material jetting. Potential hazards associated with this 3D printing method are emission of particulate matter and VOCs, and use of lasers or heat sources. Other hazards relate to the biological nature of the process including use and handling of biomolecules and living cells, and chemicals required for sterilization. This process is shown in the photo below.

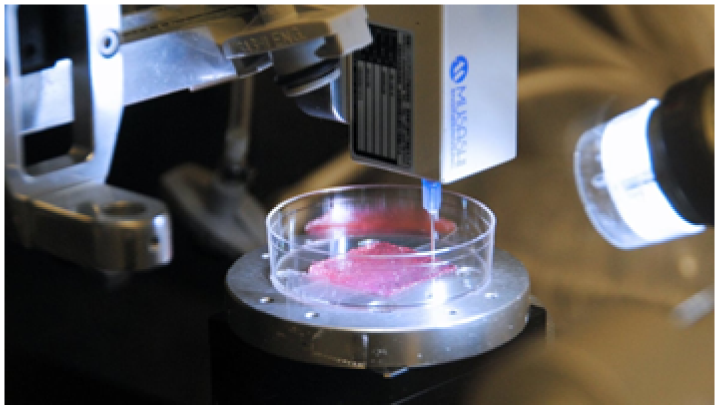


Table 1 – 3D Printing Methods and Hazards				
Method/Example	**Feedstock Materials**	**Feedstock Form**	**Process**	**Prominent Hazards**
Material extrusion, e.g., Fused deposition modeling	Thermoplastics, e.g., Polylactic acid, acrylonitrile butadiene styrene	Spooled filament	Electrical heating, element induced, melting and cooling	Inhalation of VOCs and particulate; burns
Powder bed fusion, e.g., Selective laser sintering	Metal, ceramic or plastic, e.g., Silicon carbide, aluminum	Powder	High-powered laser or electron beam heating	Inhalation or dermal exposure to powder; explosion; non-ionizing radiation
Vat photopolymerization, e.g., Stereolithography	Photopolymer, e.g., Acrylates, epoxides	Liquid resin	Ultraviolet (UV)-laser induced curing	Inhalation of VOCs; dermal exposure to resins and solvents; UV exposure
Material jetting, e.g., Polyjet	Photopolymer or wax, e.g., Acrylates	Liquid ink	UV-laser induced curing	Inhalation of VOCs; dermal exposure to resins and solvents; UV exposure
Binder jetting, e.g., Drop-on-powder printing	Metal, ceramic or plastic, e.g., Calcium carbonate, acrylic powder	Powder	Adhesive	Inhalation or dermal exposure to powder; explosion; VOCs
Sheet lamination, e.g., Laminated object manufacturing	Metal, ceramic or plastic, e.g., Carbon fiber, nylon	Rolled film or sheet	Adhesive or ultrasonic welding	Inhalation of fumes, VOCs; shock; non-ionizing radiation
Direct energy deposition, e.g., Directed light fabrication	Metal, ceramic, e.g., Stainless steel, copper	Powder	Laser, electron beam or plasma arc	Inhalation or dermal exposure to powder; explosion; non-ionizing radiation

References

https://www.cdc.gov/niosh/docs/2020-115/pdfs/2020-115.pdf

https://www.cdc.gov/niosh/docs/2020-114/pdfs/2020-114.pdf?id=10.26616/NIOSHPUB2020114

https://www.cdc.gov/niosh/docs/2024-103/pdfs/2024-103.pdf

https://chemicalinsights.org/wp-content/uploads/2023/05/UL-200B_1.pdf