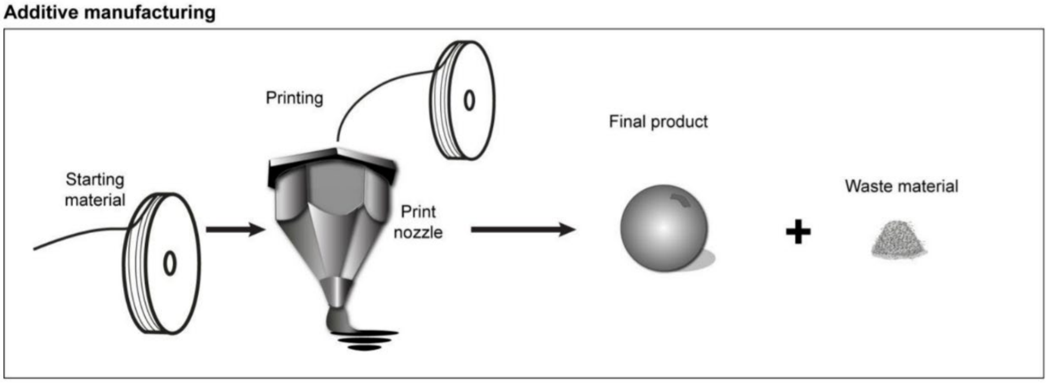
UMassAmherst | Environmental Health & Safety

3D Printers SOP

What is 3D Printing?

3D printing, also called additive manufacturing, is a process of converting the information from a digital file into three-dimensional objects. Additive processes, which are layering of various materials, including, but not limited to metals, curable resins, ceramics, plastics, nanomaterials, concrete, paper and certain edibles, are used to create 3D printed objects.

Additive manufacturing



Sources: GAO (analysis); Art Explosion (images). | GAO-15-505SP

There are many different types of 3D printing, and the technique used is controlled by the material that is printed and the desired properties in the finished product. As a result, potential exposures largely depend upon what the 3D printing method is and the material that is being used.

A variety of materials and chemicals can be used in 3D printing. Some common materials and chemicals include, but are not limited to:

1. Polymers
   - Acrylonitrile-butadiene-styrene (ABS)
   - Polylactic acid (PLA)
   - Polycarbonate (PC)
   - Poly(vinyl alcohol) (PVOH, PVA, or PVAl)
   - Poly (ethylene terephthalateco-1, 4-cylclohexylenedimethylene terephthalate) (PETG)
2. Solvents
   - Dimethyl fumarate

ABS filaments
Source: https://www.amazon.com/MakerBot-ABS-Filament-1kg-Spools/dp/B00K2DCN5U

- Isopropanol
- Acetone
- Methyl Ethyl Ketone (2-Butanone)

3. Powder Metals
    - Aluminum
    - Titanium
    - Steel

Powder metals
Source:
https://www.materials.sandvik/en/products/metal-powder/

4. Nanomaterials
    - Iron nanoparticles (nFe) – steel sintering
    - Silver nanoparticles (nAg) - sintering and conductivity
    - Carbon black nanoparticles (nCB) and carbon nanotubules (CNTs) - conductivity, stiffness, tensile strength
    - Silicon oxide nanoparticles (nSiOx) - polymer strength

What are the hazards?

Physical	Chemical
UV light, laser, and radiation (can cause eye and skin burns) **Fire or explosion** **Ergonomic** (lifting materials, equipment, printed parts and machine maintenance) **Cutting and grinding injuries** (using sharp tools, including scalpels, screwdrivers and other hand tools) **Falls and falling objects** **Burns** (hot surfaces, such as print head block and UV lamp) **Crushing injuries** **Electrical shock** (high-voltage power supplies) **Noise generation** **Heat generation**	**Fine particles (FPs) and ultrafine particles (UFPs)** Fine particles have diameters less than 2.5 microns. UFPs have diameters less than 0.1 microns (i.e., are nanoparticles) and can penetrate and irritate the skin, lungs, nerves and brain tissues. Elevated FP and UFP levels may cause adverse health effects (e.g. eye, nose and throat irritation, cardio-pulmonary mortality, strokes and asthma). **Outgassing or Volatile Organic Compounds** may cause headaches, respiratory irritation and eye irritation. **Compressed gases** (e.g. argon and nitrogen). **Powdered metals** (e.g. aluminum, titanium, stainless and nickel alloy steels).
Biological	
The use of 3D printing has recently been extended to the medical field. Biological hazards can be posed when printing biological materials (e.g. cells for engineered tissue generation) resulting in potential exposure to biological aerosols created during this process.	

Occupational Exposure Limits (OELs)

To date, little is known about occupational exposures and potential exposure-related health effects related to 3D printing technology and as such, it requires further evaluation and research. Consequently, very few materials and chemicals used in 3D printing processes have set OELs. Ultrafine particles (UFPs), in particular, are not well characterized due to inconsistent research methods and metrics in the literature making it difficult to understand the impacts of exposure. As a result, OELs have yet to be established for UFPs. Median estimates of 3D printer UFP emission rates range from ~10^8 to ~ 10^{11} particles/min across various testing conditions (e.g. filament type, and bed temperature), which, assuming normal conditions, would elevate UFP concentrations to 10 times higher than what is typically observed in office and laboratory settings. Under the Clean Air Act, the Environmental Protection Agency (EPA) is required established regulatory limits for outdoor levels of particulate matter less than 2.5 microns in diameter (PM 2.5), a category which includes UFPs. While there is no regulatory limit set for indoor concentrations of UFPs, the EPA urges to limit exposure as much as possible given the well-established link between PM 2.5 and adverse health effects.

For more information on OELs, please refer to OSHA PELs Table Z-1 (https://www.osha.gov/dsg/annotated-pels/tablez-1.html), NIOSH Pocket Guide to Chemical Hazards (https://www.cdc.gov/niosh/npg/default.html) and ACGIH® 2019 Threshold Limit Values.

What Activities Could Pose a Risk?

Risk of exposure to 3D printing processes depends on the materials used and the processes by which the materials are used. 3D printing materials used in the lab are primarily found in one of three forms: powder, resin, or filaments. Possible routes of exposure include: inhalation, absorption, ingestion, and inoculation. Inhalation is a likely route of exposure for VOCs and particle emission from 3D printing processes, depending on the materials used. Absorption can occur as a result of dermal contact with some 3D printing materials (e.g. resins and solvents) and waste. Ingestion could occur from contaminated hand-to-mouth contact, or from swallowing materials cleared from the respiratory tract. Inoculation is possible if sharps are used with 3D printing materials and printed objects.

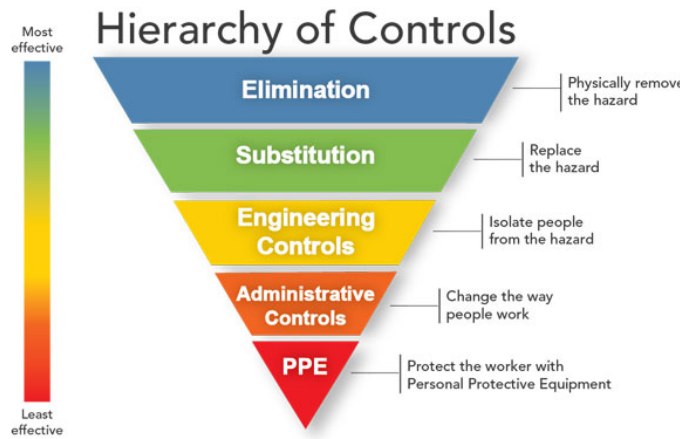
Activities that could present a risk of exposure include, but are not limited to:

- Staying in a poorly ventilated room with multiple 3D printers.
- Attempting to override interlocks and other safety devices on 3D printers.
- Not following manufacturer's instructions and recommendations.
- Operating and staying next to non-enclosed 3D printers, or cleaning 3D printers without appropriate control measures.
- Handling some types of 3D printing materials, especially powders, in a non-enclosed system.
- Operating faulty 3D printers (e.g. printer is not clean or not in good working condition).
- Using sharp tools, such as scalpels and screwdrivers, with 3D printing materials and printed objects.
- Improperly cleaning up spills or waste material.
- Touching hot surfaces when 3D printers are operating.
- Improperly cleaning dust collection systems used to capture VOCs and particle emissions.
- Conducting maintenance on 3D printers without enclosure.
- Operating 3D printers with UV light, laser, or radiation without protections.
- Handling some types of 3D printing materials without gloves, such as powders, resins, binders, solvents and other chemicals.

How Can Exposures Be Minimized?

When working with 3D printers, or any other hazardous material, always conduct a thorough risk assessment and employ the hierarchy of controls to minimize risk. Some specific applications of the hierarchy of controls to the hazards of 3D printer applications are listed below.

Always apply the controls in the order of most effective to least effective (see graphic), and apply as many controls as possible to reduce the risk to the lowest achievable level.



Elimination/Substitution

- Use low emitting materials and 3D printers.
- Choose materials of relatively low hazard (e.g. using PLA instead of ABS).

Engineering Controls

- Ensure the room has adequate air supply and exhaust to dilute and eliminate 3D printer emissions.
- Utilize local ventilation and enclosures to control/reduce emissions from 3D printers (e.g. snorkel exhaust, fume extractors, fume hoods, or filtered enclosures).
- Operate 3D printers in enclosed ventilated racks that exhaust to the outdoors or are filtered. The majority of 3D printer emissions are nanoparticles (including ultrafine particles) and VOCs to a lesser extent. Exhausting the air from printers through a room air cleaner with a high-efficiency particulate air (HEPA) and activated charcoal filtration unit can remove these contaminants.

Administrative Controls

- All lab personnel must read the operating instructions be trained on the safe and efficient use of the printer and related materials before operating 3D printers.
- Only authorized personnel should be allowed to operate 3D printers.
- 3D printers must be installed, operated, and maintained according to the manufacturer's instructions.
- Clean up work areas promptly after use and properly dispose of dust, scraps, and waste.
- Turn off, unplug, and cool down the unit prior to cleaning or maintenance.
- Review safety data sheets for all materials used in a 3D printing process prior to use.
- If working with or producing metal dusts, a Class D fire extinguisher must be on hand and stored in an accessible location. Standard CO_2 and dry chemical extinguishers are appropriate for most ink jet, thermoplastic, or photopolymer printers.
- Always use and properly maintain the manufacturer's supplied controls and filter system.
- Position work stations away from 3D printers (i.e., in a different room) to minimize exposure to emissions.

- Coordinate work schedules such that 3D printers operate during off-hours, or when the space is least occupied.
- Wait 15 min before entering the room after the printing procedure is completed to allow particles to settle and reduce exposure. Similarly, allow equipment to ventilate before servicing.
- Make sure the inert gas used for 3D metal printers is not leaking and the valve is shut off before maintaining, repairing, or conducting any activity that requires the removal of the enclosure.

Personal Protective Equipment

- Safety glasses or goggles appropriate for the chemical hazards must be used, particularly when loading liquid monomer reservoirs or using caustic cleaners. Face shields should be used in addition to eye protection if significant splashing is likely.
- Wear appropriate gloves during processes involving hot surfaces (thermal gloves), sharp tools (cut resistant gloves), irritating plastics and corrosive chemicals (disposable nitrile gloves or other chemical resistant gloves, as appropriate). Contact EH&S for any questions on glove selection.
- In cases where engineering controls do not provide sufficient protection for inhalation exposure, NIOSH certified N95 respirators can be used to reduce exposure. Powered air purifying respirators (PAPRs) with HEPA filters and a flame-resistant (FR) hood are recommended for powdered metal printers, particularly when loading, leveling, filter changing, extracting or cleaning involves pyrophoric and/or reactive materials. EH&S will work with you to determine the appropriate respirator based on a risk assessment for the dust generating processes. Respirator users must enroll in the University's Respiratory Protection Program (https://ehs.umass.edu/respiratory-protection-program).

For 3D printer users using base bath solutions to clean printed parts:

- Use less hazardous materials if possible, such as sodium percarbonate (i.e. OxiClean) instead of sodium hydroxide solutions.
- Eye washing facilities, such as eye wash stations or eye wash bottles, must be present.
- Base baths should be (1) the smallest volume and concentration necessary for cleaning, (2) Placed within secondary containment near the sink at an appropriate height, (3) kept away from acids, (4) covered when not in use, and (5) labeled with the full chemical name and percent concentration.
- Ensure tongs are appropriate for gripping and sufficiently long. Parts that are dropped in the bath can create splashing and result in caustic chemical exposure.
- Avoid skin and eye contact with the base bath solution by wearing appropriate PPE, including safety glasses/goggles, lab coats and long chemical resistant gloves. Additionally, a face shield and apron is recommended.

Waste Handling

Several different waste streams may be generated during the 3D printing processes.

1. **UV-curable resins:** If the resins are fully cured and solid, please cross out corrosive markings and dispose in regular trash.

2. **Metal powders:** Metal powders collected in the 3D printer collection containers should be handled as hazardous waste and should follow the disposal procedure set by EH&S.
3. **Base bath solutions:** Base bath solutions used in the finishing steps of 3D printing processes should be handled as hazardous waste when the solutions are spent or no longer utilized.

All lab waste containing metal powders, base bath solutions or solvents should be handled as hazardous waste. This includes contaminated debris (e.g. PPE, plastic, bench covers). Contaminated waste should be placed in an appropriate container and labeled. The label should indicate relative amounts (by percentage) of all constituents within the waste container. Complete a Hazardous Materials Pickup Request Form in CEMS to have the waste collected by EH&S staff.

Exposure and Spill Procedure

In the event of a spill involving 3D printing materials that are considered hazardous according to GHS classification (including but not limited to metal powders, resins, base bath solutions, solvents and nanomaterials) that does not involve an exposure, the material may be cleaned up if it is safe to do so.

- Ensure that cleaning up the material will not generate airborne dust or aerosols. Use wet methods when appropriate for solid materials.
- Place all items used for cleanup in a labeled hazardous waste container and request a pickup through CEMS.
- If at any point you are uncomfortable cleaning up the spill or require assistance, stop and call EH&S (413-545-2682).

Exposures to hazardous 3D printing materials should follow the general procedures for exposures to hazardous materials outlined in the University's Chemical Hygiene Plan.

For a major exposure requiring the use of a drench shower or eyewash:

- Have someone call 911 (report the building name, room number, and street address) or 413-545-3111 (or simply 5-3111 from a campus line) to report the incident and request medical help. Have someone obtain the SDS for the material (if there is one) and provide it to the first responders when they arrive, if possible.
- Help the affected individual to position their head over the eyewash and activate it, or position them under the drench shower and activate it as appropriate.
    - Always ensure your own safety before helping others. Only help if it is safe for you to do so.
    - Wear gloves, safety glasses, and a lab coat.
- If using an eyewash: Instruct the affected individual to open their eyes and roll them around while the water is flowing. Help them to hold their eyes open if necessary and safe to do so.
- If using a drench shower: Remove all clothing from the affected area while under the shower.
- Flush the affected area for 15 minutes with water.

For minor exposures such as small cuts or a spill to readily accessible extremities (e.g., hand):
- Flush the affected area in a sink equipped with potable water for at least 15 minutes.

- Go to University Health Services (UHS) for medical evaluation, and tell them you have had a lab exposure.
- Provide the SDS for the material if possible.
- Notify EH&S (413-545-2682) as soon as possible and complete the lab incident form (https://ehs.umass.edu/lab-incidents-and-lab-incident-report-form).

References and Additional Resources

1. ISO/TC 261 Technical Committees. https://www.iso.org/committee/629086.html
2. ASTM International Committee F42. https://www.astm.org/COMMITTEE/F42.htm
3. ASTM International. AM standards Structure and Primer. https://www.astm.org/COMMIT/F42_AMStandardsStructureAndPrimer.pdf
4. ANSI/CAN/UL 2904-2019. Standard Method for Testing and Assessing Particle and Chemical Emission from 3D Printers.
5. NIOSH Slides. Overview of Additive Manufacturing and Potential Occupational Hazards. https://orau.org/ihos/downloads/meetings/support-files/2019/NIOSH/GRoth--AM_Proc_Haz.pdf
6. NIOSH Science Blog. Characterizing 3D Printing Emissions and Controls in an Office Environment. https://blogs.cdc.gov/niosh-science-blog/2018/08/16/3d-printing/
7. Steinle, P., 2016. Characterization of emissions from a desktop 3D printer and indoor air measurements in office settings. Journal of occupational and environmental hygiene, 13(2), pp.121-132.
8. Azimi, P., Zhao, D., Pouzet, C., Crain, N.E. and Stephens, B., 2016. Emissions of ultrafine particles and volatile organic compounds from commercially available desktop three-dimensional printers with multiple filaments. Environmental science & technology, 50(3), pp.1260-1268.
9. Oskui, S.M., Diamante, G., Liao, C., Shi, W., Gan, J., Schlenk, D. and Grover, W.H., 2015. Assessing and reducing the toxicity of 3D-printed parts. Environmental Science & Technology Letters, 3(1), pp.1-6.
10. Occupational Safety and Health Administration (OSHA) Annotated TABLE Z-1. https://www.osha.gov/dsg/annotated-pels/tablez-1.html
11. ACGIH® 2019 Threshold Limit Values for Chemical Substances in the Work Environment. See http://www.acgih.org/.
12. NIOSH Pocket Guide to Chemical Hazards. https://www.cdc.gov/niosh/npg/default.html
13. NIOSH slides. Additive Manufacturing: Observations, Hazards, and Opportunities. https://www.turi.org/Our_Work/Training/Continuing_Education/Recent_Training_Presentations/Continuing_Education_Conference_Spring_2018/Additive_Manufacturing_Observations_Hazards_and_Opportunities
14. NIOSH Science Blog. Potential Hazards of Additive Manufacturing. https://blogs.cdc.gov/niosh-science-blog/2019/04/09/am/
15. Baldauf, R. Ultrafine Particle Metrics and Research Considerations: Review of the 2015 UFP Workshop. In Proceedings, EPA Workshop - State of Science on Effect of Ultrafine Particles, RTP, NC, February 04, 2015. MPS Multimedia Print Service, Domodossola, Italy, 1054, (2016).
16. Emissions of Ultrafine Particles and Volatile Organic Compounds from Commercially Available Desktop Three-Dimensional Printers with Multiple Filaments. Parham Azimi, Dan Zhao, Claire Pouzet, Neil E. Crain, and Brent Stephens. *Environmental Science & Technology* **2016** *50* (3), 1260-1268 DOI: 10.1021/acs.est.5b04983.

17. Setting and Reviewing Standards to Control Particulate Matter (PM) Pollution. https://www.epa.gov/pm-pollution/setting-and-reviewing-standards-control-particulate-matter-pm-pollution.