# **3D Printing/ Additive Manufacturing Safety**

Introduction

3D printing, also known as Additive Manufacturing, is the process by which a three-dimensional object is built from a computer model by laying down successive layers of material. Production processes and materials vary greatly between 3D printing applications, each having its own unique set of health and safety hazards.

## **3D Printer Types**

3D printing methods are typically organized into seven categories based on the way the material is joined:

* Material Extrusion – The most common form of Material Extrusion is Fused Deposition Modeling (FDM), in which a thermoplastic filament such as ABS (acrylonitrile butadiene styrene) or PLA (polylactic acid) is melted and deposited in layers by a moving nozzle. Most low-cost, consumer-grade desktop printers are FDM and use ABS or PLA.
* Vat Polymerization – The most common form is known as stereolithography (SLA). It works by focusing a UV laser on a photopolymer resin, which hardens the resin in successive layers.
* Material Jetting – Selectively deposits droplets of feed material, such as inks, onto a build platform. When the droplets cool and solidify, the next layer is deposited on top.
* Binder Jetting – A liquid binder is sprayed onto a bed of ceramic or metal powder, causing it to solidify. The process is repeated in successive layers to build the 3D object.
* Powder Bed Fusion – Most common form is Selective Laser Sintering (SLS). Plastics, metals, ceramics, or glass powders are fused together using lasers or an adhesive to form a solid structure.
* Directed Energy Deposition (DED) – A metal powder or wire is melted at the same time it is being deposited by a moving print head.
* Sheet Lamination – Creates 3D objects by using a laser or other sharp blade to cut and bond thin-layered materials (e.g., paper, aluminum foil) together layer-by-layer.

*Note: This fact sheet is not intended to replace Safety Data Sheets or other safety documents provided by manufacturers.*

Hazards

The hazards of 3D printing are as varied as its applications:

* Chemical Vapors – Many filaments and photopolymer resins have been shown to produce Volatile Organic Compounds (VOCs) when heated in 3D printing processes. Exposure to VOCs may cause short-term health effects (headache, nausea, breathing problems, and eye/nose/throat irritation) and long-term health effects (cancer). Organic solvents used in post-processing pose an inhalation hazard.
* Inhalable Particles – Plastic filaments produce inhalable nanoparticles (NPs) when heated during 3D printing. Additionally, the use of NP-containing media can emit inhalable NPs into the surrounding atmosphere. The health effects of NPs are not well understood, but preliminary research suggests that inhalation is associated with cardiovascular and pulmonary diseases. Acute and chronic inhalation exposure to metal powders can cause lung damage resulting in chronic respiratory diseases (such as asthma, chronic bronchitis, or emphysema) and some metals may be toxic or carcinogenic.
* Dermal and Eye Exposure – Repeated skin exposures to photopolymer resins and some metals (such as nickel) can cause allergic dermatitis. Some dissolvable support materials are removed by placing prints in a heated corrosive bath containing sodium hydroxide or other corrosive chemicals. Exposure to these chemicals can cause serious chemical burns, scarring, and blindness.
* Vapor Baths – Some filament printed objects can be smoothed or “polished” by placing them in a closed vessel filled with a small quantity of acetone or other organic solvent, which vaporizes and reacts with the plastic. The solvents are usually flammable and can cause symptoms when inhaled such as headache, nausea, and respiratory tract irritation.
* Biological Material – Printers using biological material can produce aerosols which may be inhaled or deposited onto nearby surfaces.
* Heat – Components such as UV lamps, motors, heat beds, and print heads become hot during operation and can cause burns when touched.
* Flammability – Fine metal powders such as aluminum, aluminum alloys, steel, and titanium can spontaneously combust under normal atmospheric conditions (known as pyrophoricity). Thermoplastics can be flammable. Organic solvents (e.g., acetone) can combust when exposed to a heat source. Chemicals used in bed preparation such as hairspray are flammable. Printers can overheat and catch fire if thermal runaway protection is not activated in the firmware or is not working properly.
* Inert Gas – Some 3D printers use inert gases, such as nitrogen or argon, to create an oxygen-deficient atmosphere in the printing chamber or use an inert gas as part of the aerosolization and deposition process. Inert gas leaks can displace oxygen in the room and present an asphyxiation hazard.
* Electric Shock – 3D printers are high voltage pieces of equipment and interaction with unguarded electrical components (e.g., the UV lamp power supply or the printer power supply) may result in exposure to high voltage.
* Mechanical Hazards – Hands and fingers may be pinched by moving printer components while in operation. CNC post-processing of metal parts presents mechanical and noise hazards.
* Sharps – To remove the support material, spatulas, razors, scalpels, and other sharps are commonly used. Printed metal parts may also have sharp edges or points. This can lead to cuts and abrasions.
* Ultraviolet Light/Lasers – Eye exposure to the UV lights used in SLA printers can cause temporary or permanent vision loss. Directed Energy Deposition and Powder Bed Fusion printers often use powerful Class 4 lasers which can cause permanent eye injury from direct or reflected light.

Best Practices

**NOTE**: Do not use 3D printers to create deadly weapons without first consulting with OEHS and obtaining University approvals in accordance with [WSU Campus Safety Ordinances](https://bog.wayne.edu/code/2-87-03).

Before purchasing and implementing a 3D printing system, conduct a risk assessment to understand the unique hazards of the system and the appropriate controls necessary to protect lab personnel. The risk assessment will help determine if the workspace is appropriately equipped for a 3D printing system and has sufficient ventilation. The National Institute for Occupational Safety and Health (NIOSH) has risk assessment documents for 3D printing with filaments and metal powders to help guide users (see References section for links). Labs are also encouraged to consult with OEHS (7-1200).

Once systems are purchased and setup, labs must develop a [Laboratory Specific Standard Operating Procedure (SOP)](https://research.wayne.edu/oehs/chemical/19-002st_lab_specific_chemical_sop_template.docx). This should not only include the steps for system use and maintenance, but also outline the specific hazards involved and the required safety controls. Use the SOP to train new personnel.

## **General Safety Provisions**

* When possible, use a printer that has been ANSI/CAN/UL 2904 certified to produce fewer emissions.
* Before operating a 3D printer, ensure you are familiar with the correct, safe operation of the printer.
* Always follow the manufacturer’s instructions on printer setup and usage, review Safety Data Sheets (SDS) of materials/chemicals to be used and review the Laboratory Specific SOP.
* Restrict access to authorized personnel and who is essential to running the system.
* Never bypass safety controls or defeat interlocks once the printing process has started.
* Do not store flammable liquids or combustible metal powders near 3D printers or inside the enclosures. The heated components of 3D printers can cause these to catch fire.
* Areas where plastics, metal powders and toxic support materials are used must be well ventilated (at least 6 air changers per hour) to reduce personnel exposures and the risk of fire or explosion.
* Place 3D printers in ventilated enclosures, such as a chemical fume hood or an enclosed filtration system. Enclosures and filtration systems may be available from the printer manufacturer and are available from other vendors. This will decrease the risk of hand/finger pinches from moving parts and reduce air contamination. Keep doors to enclosures closed as much as possible.
  + A ductless fume hood or similar filtered ventilation may be acceptable for some printer types/materials Note, these ventilation devices are only capable of filtering limited types of chemicals and particles. The HEPA and gas/vapor filters must also be regularly replaced according to manufacturer's guidelines and labs should document filter changes.
* UV light sources and lasers should be enclosed with opaque materials or materials that can block these types of light to prevent eye and skin exposures. Laser safety glasses must be used with exposed lasers. Review [laser safety requirements](https://research.wayne.edu/oehs/training/lasers) and consult with OEHS before installing lasers.
* Know the locations of emergency equipment relevant to the hazards of your printer, such as appropriate fire extinguishers, safety showers, and eyewash stations. A functioning safety shower and eyewash station must be within 10-second travel time (approximately 55 feet) of work areas where corrosives are used. Keep the safety shower and eyewash unobstructed and easily accessible. Plumbed eyewashes must be tested weekly and documented using the [Emergency Eyewash Maintenance Log](https://research.wayne.edu/oehs/docs/eyewash-log-sheet.doc).

## **Filaments and Resins**

* Most plastic filaments produce toxic ultrafine particles and volatile organic compounds. The emissions of PLA are less hazardous than other plastics and is the preferred filament when feasible.
* To minimize VOC and particle emissions, operate the printer extrusion nozzle and base plate at the lowest possible temperature. Use printing materials that produce lower emissions.
* Thoroughly clean the printer nozzle and print bed before each use. Refer to manufacturer instructions for proper cleaning.
* If the printer nozzle jams, turn off the printer and allow it to ventilate for 10 minutes before opening the enclosure. Concentrations of vapors and particles are at the highest at the beginning of the print run and when a printing failure occurs.

## **Metal Powders**

All metal powders of any composition and particle size should be treated as hazardous, including alloys and mixtures containing non-metallic substances. Many metal powders can form explosive dust clouds. Personal exposure can cause chronic health effects, due to physical damage to lungs or due to the metals being toxic or carcinogenic.

The following safety practices should be followed for any operation handling or producing metal powders:

* Keep a Class D fire extinguisher or extinguishing agent within reach and be trained on appropriate use.
  + Note, Class ABC fire extinguishers, which are typically found in buildings on campus, are not appropriate for metal fires and may make the fire worse. Contact the WSU Fire Safety Office to purchase a Class D fire extinguisher. Class D fire extinguishing agent can also be purchased from vendors such as Fisher Scientific or Ansul.
* Store metal powders in a designated area separated from other chemicals, especially away from flammable liquids and oxidizers.
* Store and use metal powders away from sources of water. The oxidative reaction between water and some metal powders can be violent. If a liquid is needed to cleanup metal powders, use a solvent absorbent pad or a small amount of ethanol and paper towel.
* Conduct activities in a manner that minimizes the release of airborne dust and the possibility of spillage. Activities which create an increased risk include loading powders manually into the machine and sieving powders outside of the machine. If available, purchase printing systems which include enclosed powder loading and sieving.
* Use HEPA-filtered and fire/explosion proof ventilation systems. The system should be designed to minimize the buildup of static electricity. PPE must be worn when changing filters and filters should be disposed of as hazardous chemical waste.
* Only use vacuums designed for use with metal powders (electrostatic dissipative). Conventional vacuums can cause fire or explosion due to static electricity buildup and unprotected motors. Vacuums should be electrically grounded.
* Use natural bristle brushes (not synthetic) and use conductive, non-sparking tools/scoops/dustpan (not plastic). Regularly clean work areas to minimize the buildup of metal dusts.
* 3D metal printers typically use a significant amount of argon or nitrogen to displace oxygen at the point of printing. This may require the use and storage of several gas cylinders. It is recommended that an oxygen sensor be installed to warn personnel if oxygen levels in the room drop to or below 19.5%.

**NOTE**, in some cases, metal samples created through 3D printing/additive manufacturing may need to be treated with solutions containing hydrofluoric acid. The use of hydrofluoric acid requires prior approval by the WSU Chemical Safety Committee. Contact the Chemical Hygiene Officer (7-1200 or oehs@wayne.edu) for information regarding protocol submission and approval by the WSU Chemical Safety Committee.

## **Post-Printing Processing**

* Some printed objects may require processing in a corrosive solution bath. When possible, use ready-made products that are less hazardous, such as [Techni Print brand cleaning concentrate](https://www.technic.com/applications/3d-printing/3d-printing-chemistry).
* The chemicals used in corrosive baths can cause chemical burns and permanent blindness. Wear appropriate PPE (listed in the PPE section below). In the event of an eye or skin exposure, flush immediately for 15 minutes, and have another employee call WSU Police (7-2222).
* When mixing a new corrosive bath, fill the container with water first and slowly add the corrosive powder/liquid second.
* Use instruments such as tongs when adding and retrieving objects from the bath. Never add or remove objects with your hands, even with gloves on.
* All liquids used in post-printing baths should be disposed of as hazardous waste via OEHS.
* Sanding of printed objects creates powders which may cause respiratory irritation and/or long-term adverse health effects. Review SDS for safety concerns and appropriate respiratory protection.

## **Using Organic Solvents**

Organic solvents are flammable chemicals that readily vaporize at room temperature. Examples include acetone and alcohols. They are sometimes used with FDM printers for bed preparation and surface finishing. They are also sometimes used for cleaning metal printed objects.

* Always ensure a functioning and charged ABC fire extinguisher is nearby in the case of a fire.
* Do not use organic solvents or hairspray on printers whose components are heated.
* Only store organic solvents in [flammable or explosion proof refrigerators](https://research.wayne.edu/oehs/chemical/19-007f_fact-sheet-refrigerators-flammables_ada.pdf). Storage in a regular refrigerator can result in an explosion.
* Use organic solvents inside of a chemical fume hood when possible.

# Personal Protective Equipment (PPE)

In addition to proper street clothing (long pants or equivalent that cover legs and ankles, close-toed non-perforated shoes that completely cover the feet), the following activities require specific PPE:

| **Filament or Resin Handling** | **Metal Powder Handling** | **Corrosive Baths or Treatments** | **Organic Solvent Use** |
| --- | --- | --- | --- |
| Laboratory coat | Flame resistant lab coat, such as Nomex. | Laboratory coat | Flame resistant lab coat, such as Nomex. |
| Safety glasses | Safety glasses | Safety goggles | Safety glasses |
| Nitrile gloves | Nitrile, butyl, or neoprene gloves | Nitrile gloves that cover the cuffs of the lab coat | Nitrile, butyl, or neoprene gloves |
|  | \* P100 half or full face respirator. Metal powders may contain oil residues. “P” designated respirators are designed to be compatible with oils. | Chemical-resistant apron |  |
|  | Cut resistant gloves are recommended for handling printed materials with sharp edges or points. Refer to 2016 ANSI/ISEA 105 Cut Resistance Standard for appropriate cut resistance level. |  |  |

Ensure that PPE is kept in good condition. Regularly check PPE for cracks, holes, and signs of wear.

**\* Note**: The use of a respirator requires participation in the [WSU Respiratory Protection](https://research.wayne.edu/oehs/health-safety/respirators) program, including training and fit testing. Contact OEHS (7-1200) for training and referral for fit testing.

# Training

All individuals operating 3D printers should complete the following training.

* Laboratory Safety Training (through [CITI](https://about.citiprogram.org/)) (to be completed annually)
* Hazard Communication (through [CITI](https://about.citiprogram.org/))
* Laser Safety (if the printer includes a laser) (through [CITI](https://about.citiprogram.org/))
* Lab Specific Training with PI or lab manager (documented on Laboratory Specific SOP. Labs can create their SOP using the OEHS [Lab Specific SOP template](https://research.wayne.edu/oehs/chemical/19-002st_lab_specific_chemical_sop_template.docx).)

Individuals conducting 3D printing using human biological materials or animal biological materials infected with human pathogens must also take Biosafety/Bloodborne Pathogens training (through [CITI](https://about.citiprogram.org/) completed annually).

Disposal

* Chemical Waste – Many of the materials used as part of the 3D printing process require disposal as hazardous chemical waste, including resins, combustible metal powders, corrosive liquids, organic solvents/flammable liquids, and filters used in the filtration exhaust systems.
  + Some plastic powders created during sanding of printed objects may be considered non-hazardous but can create respiratory irritation. These should be sealed in a plastic bag or other sealable container before placing in regular trash.
* Biological Waste – Disposable solid items contaminated with biological materials must be disposed of in a biohazard bin. Non-disposable solid items must be autoclaved. Liquid biological waste can be treated with bleach (10% final concentration) for at least 30 minutes before drain disposal with copious amounts of water.
* Sharps – All sharps (e.g., glass pipettes, pipette tips, needles, syringes, razor blades) must be disposed of in a sharps container. Sharps containers can be obtained from OEHS through the [Biological Waste Pickup Request form](https://research.wayne.edu/oehs/hazardous/biological-waste).

Do not dispose of waste by dumping down a drain or discarding in regular trash containers, unless authorized in writing by OEHS. [Submit requests to OEHS](https://research.wayne.edu/oehs/hazardous) for waste containers, labels, and waste collection. Also, refer to the [OEHS Hazardous Waste Management web page](http://research.wayne.edu/oehs/hazardous/index.php) and [WSU Chemical Hygiene Plan](http://research.wayne.edu/oehs/pdf/chemical-hygiene-plan.pdf) for more information.

Emergency Response & Contacts

* **WSU Public Safety: (**313) 577-2222, emergency transportation
* **Henry Ford Occupational Health – Harbortown**

3300 East Jefferson, Suite 100

Detroit MI 48207

(313) 656-1618

Monday – Friday 8:00 AM to 6:30 PM

* **For help outside of health clinic hours**

**Detroit Receiving Hospital – Emergency Room:** (313) 745-3000

**OR**

**Henry Ford Hospital – Emergency Room**: (313) 916-8742

* **Office of Environmental Health and Safety:** (313) 577-1200, spills or clean-up
* **WSU Fire Marshall:** (313) 577-3110.

References

1. [3D Printers and Human Health Impacts](https://chemicalinsights.org/3dp/#/lessons/ycaPd_aK4-yvTAxCjxZ4_9X4ai1-dmNb). Institute of Underwriters Laboratories - Chemical Insights
2. [3D Printing Safety at Work](HTTPS://WWW.CDC.GOV/NIOSH/NEWSROOM/FEATURE/3DPRINTING.HTML). (2020, December 7). National Institute for Occupational Safety and Health (NIOSH)
3. [3D Printing/Additive Manufacturing Safety Guide](HTTPS://EHS.MSU.EDU/_ASSETS/DOCS/CHEM/3D-PRINTING-SAFETY.PDF). (2020, May). Michigan State University - Environmental Health & Safety
4. Azimi, P., Zhao, D., Pouzet, C., Crain, N. E., & Stephens, B. (2016). Emissions of Ultrafine particles and volatile organic compounds from commercially available desktop three-dimensional printers with multiple filaments. Environ Sci Technol, 50(3), 1260-1268.
5. Glassford, E., Dunn, K. L., Dunn, K. H., Hammond, D., & Tyrawski, J. (2020, March). [3D Printing with Filaments: Health and Safety Questions to Ask](HTTPS://WWW.CDC.GOV/NIOSH/DOCS/2020-115/). National Institute for Occupational Safety and Health (NIOSH)
6. Glassford, E., Dunn, K. L., Dunn, K. H., Hammond, D., & Tyrawski, J. (2020, March). [3D Printing with Metal Powders: Health and Safety Questions to Ask](HTTPS://WWW.CDC.GOV/NIOSH/DOCS/2020-114/). National Institute for Occupational Safety and Health (NIOSH)
7. Kim, Y., Yoon, C., Ham, S., Park, J., Kim, S., Kwon, O., & Tsai, P. J. (2015). Emissions of nanoparticles and gaseous material from 3D printer operation. Environ Sci Technol, 49(20), 12044-12053.
8. McCallion, R. (2019, October 30). [3D Printing: Potential Hazards and Risk Review](HTTPS://CPSC-D8-MEDIA-PROD.S3.AMAZONAWS.COM/S3FS-PUBLIC/3DPRINTINGPOTENTIALHAZARDSANDRISKREVIEW10302019.PDF). U.S. Consumer Product Safety Commission
9. [Reducing exposures during 3-D printing with plastics](HTTPS://WWW.CDC.GOV/NIOSH/NEWSROOM/FEATURE/2022PRINT3D.HTML). (2022, January 18). NIOSH