3D Printing

Introduction

Three-dimensional (3D) printing involves the layering of successive layers of material to create or replicate 3D objects. Depending on the printer, 3D objects are created through extrusion, sintering, or curing. 3D printers are now commonly used in many industries including, but not limited to, aerospace, architecture, automotive, consumer products, defense, dentistry, education, and medical fields. 3D printing has also become common in UConn labs and classrooms. Though 3D printing holds considerable potential, workforce members may also face health and safety risks if proper controls are not in place to minimize exposure.

Types

Multiple types of 3D printers are available to create three-dimensional objects. The most common types of 3D printers are listed below:

Common Types of 3D Printers	
Types	**Description**
Material Extrusion [Fused Deposition Modeling (FDM)]	Uses a thermoplastic filament (e.g., PLA, ABS), which is heated to its melting point, to create a 3D object. This is the most common type of 3D printer.
Vat Polymerization [Stereolithography (SLA)]	Uses a liquid photopolymer resin to create a model and then cure each layer of resin using an ultraviolet laser or digital processing lamp.
Material Jetting	Selectively deposits droplets of feed material onto a build platform, allows the droplets to cool and solidify, and then builds on the solidified droplets to create a 3D object.
Binder Jetting	Distributes a layer of powder onto a building platform and then applies a liquid bonding agent (i.e., a glue) to bond the particle layers together to create a 3D object.
Powder Bed Fusion [Selective Laser Sintering (SLS)]	Deposits a thin layer of plastic powder that is melted by a laser on a building platform. 3D objects are created through layer-by-layer construction in the powder bed.
Directed Energy Deposition (DED)	Uses a laser or electron beam to melt material (usually metal powders or wires) from the nozzle of a multi-axis arm as it is being deposited.

Sheet Lamination	Creates 3D objects by using a laser or other sharp blade to cut and bond thin-layered material (e.g., paper, aluminum foil, etc.) together layer by layer.

Hazards

3D printing involves the melting of plastics [Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), Polyvinyl Alcohol (PVA), Polycarbonate (PC), etc.], metals (e.g., steel, aluminum, titanium, copper, silver, gold, nickel, etc.), composites, and photopolymers. Exposure to emissions from the melting of print media may lead to negative health effects. The hazards associated with 3D printing are indicated below:

Health Hazards	
Biological Materials	3D printers used to create cells and/or engineered tissues may release biohazardous aerosols.
Corrosives	Some 3D printers require the use of corrosive baths to remove the extra material surrounding 3D printed items. Corrosives may cause severe burns and irreversible damage to tissues.
Sensitizers	3D printer by-products from the melting of thermoplastics and photopolymers can cause allergic reactions upon contact or inhalation.
Toxicity	3D printers using certain print media have been shown to emit volatile organic compounds (VOCs). Some wash systems used to remove uncured resin also emit VOC's. Some VOCs have been linked to eye, nose, and throat irritation, headaches, damage to the liver, kidney, and central nervous system, and cancer.
Ultrafine Particles (UFPs)	The health effects associated with exposure to UFPs (i.e., particles less than 100 nm) are currently being researched. Studies have indicated that exposure to UFPs at high concentrations can produce inflammatory responses in cardiovascular systems (hypertension) and respiratory systems (asthma, cough, and irritation of the eyes, nose and throat).
Ultraviolet (UV) Radiation	3D printers using lasers to melt print media can emit UV radiation. UV curing systems are also used in resin printing. Exposure to UV radiation may result in acute or chronic effects on the skin, eyes, and immune system.
Physical Hazards	
Flammability	3D printers using finely divided metal powders (e.g., aluminum, titanium, etc.) or other resins can be spontaneously combustible

	(pyrophoric), leading to fires. Contact EHS and UCFD prior to using printers with finely divided metal powders/resins.
Heat	Contact with the print head block and/or UV lamp can cause skin burns.
Electrical	Unguarded electrical components in some 3D printers could pose a risk of electrical shock.
Moving parts	3D printers with ingoing nip points and/or rotating parts can cause pinch or crush injuries.
Noise	Multiple printers working simultaneously may exceed OSHA's Noise Standard (29 CFR 1910.95), which mandates a hearing conservation program for employees exposed to an 8-hour time-weighted average (TWA) of 85 dBA or higher. Contact EHS for more information.

Training

- Workforce members working in laboratories with 3D printers are required to complete Laboratory Safety and Chemical Waste Management training through EHS.
- Workforce members working in non-lab areas with 3D printers are required to complete Hazard Communication training through EHS and maintain a Hazard Communication Program for filaments and other consumables in use.

Administrative Controls

- Purchase printers with ANSI/CAN/UL 2904 certification and Nationally Recognized Testing Laboratory for electrical and fire code compliance, if feasible.
- Workforce members using 3D printers with lasers or electron beams must ensure the printers are registered with the Radiation Safety Office and/or the State of Connecticut. Usage of 3D printers with lasers must comply with all requirements of the Laser Safety Manual, as applicable. Contact the EHS Radiation Safety Manager for more information.
- Select the lowest printing temperature to achieve the desired result.
- Choose a low-emitting printer and filament, if feasible. Use PLA (polylactic acid) filaments whenever feasible since it has lower VOC and UFP emissions than ABS and nylon.
- Ensure safety data sheets (SDSs) are present and accessible in the immediate work area for all print media and other chemical products involved in the printing process.
- Develop standard operating procedures to address 3D printing operations, maintenance, and disposal activities.
- Ensure an emergency eyewash station and safety shower are present in the immediate work area if corrosive materials are used in the printing process.

- Prohibit the use of liquid resins, caustics and solvents in spaces with carpets.
- Avoid using 3D printers in poorly ventilated environments like offices and residence halls.
- Place 3D printers away from high traffic and use areas, and away from HVAC return grilles.
- Never process biological materials in residences, offices, libraries, or classrooms.
- Never use caustics or solvents required for post processing in offices or residences.

Engineering Controls

All 3D printers must be used in well-ventilated areas with at least 4 air changes per hour. Rooms with more than three 3D-printers running simultaneously may require more air changes per hour, depending on the controls in place, and require an evaluation by EHS. All 3D printers should be fully enclosed and must be appropriately vented using one of the following methods:

- Local exhaust ventilation to the outdoors.
- A properly functioning chemical fume hood.
- A ventilated enclosure that vents to the outdoors.
- A filtration system using a HEPA filter or combination HEPA and carbon filter (depending on printer type and print media) on a fully enclosed filament-based or SLA printer (including wash and curing systems).
- Another ventilation option that has been evaluated and approved by EHS in writing.

Work Practices

- Install, use, and maintain 3D printers as indicated by manufacturer specifications.
- Equip enclosures with interlocks that pause printing when the enclosure is opened, if feasible. Never bypass interlocks or other safety controls.
- Maintain a safe distance from the printer(s) to limit inhalation of emitted particles.
- Limit the number of printers per room. Multiple 3D printers in the same room running simultaneously may be possible based on the ventilation, enclosures, and room size. Contact EHS.
- Store print media and other chemicals associated with the printing process as indicated by the manufacturer.
- Since 3D printers run for extended periods, rooms/labs should avoid altering ventilation rates based on occupancy sensors, unless local exhaust is being used to remove emissions.
- Avoid contact with heated surfaces.
- Ensure the printer has cooled down to prevent burns and reduce exposure to emissions prior to accessing the product.
- Do not eat or drink in areas where 3D printers are used.
- Using a HEPA-filtered and fire/explosion-certified vacuum to collect flammable powder waste.
- Ensure live parts on 3D printers operating at 50 volts or more are guarded against accidental contact.

- Ensure 3D printers with ingoing nip points and/or rotating parts are properly guarded (i.e., no exposed belts, gears, pulleys, or other moving parts or points of operation).
- Report safety concerns to EHS.

Personal Protective Equipment

- Wear eye protection (safety goggles, safety glasses, face shields, etc.) recommended by the manufacturer in safety data sheets/printer specifications if a risk of exposure to airborne particulates, liquid spraying, solvents, or other materials exist.
- Use chemical resistant-gloves recommended by the manufacturer while handling hazardous print media and other chemicals associated with the printing process (if applicable).
- Wear thermal gloves to prevent burns while working near hot printer heads.
- Comply with the requirements of the UConn Respirator Program if respirators are required for use with some 3D printers/print media (e.g., metal and ceramic powders) or if workforce members voluntarily choose to wear respirators.

Resources

- United States Environmental Protections Agency (USEPA). Office of Research and Development Publications. An Overview of Ultrafine Particles in Ambient Air.
- National Institute for Occupational Safety and Health (NIOSH). Control Measures Critical for 3D Printers.
- National Institute for Occupational Safety and Health (NIOSH). A Guide for Makerspace Users, Schools, Libraries, and Small Businesses
- Environmental Science & Technology. Emissions of Ultrafine Particles and Volatile Organic Compounds from Commercially Available Desktop 3D Printers with Multiple Filaments.
- Journal of Toxicology and Environmental Health. Emission of particulate matter from a desktop three-dimensional (3D) printer.