3D Printer Safety

PURPOSE

Three-dimensional (3D) printing is an additive process molding virtual objects or digital images into 3D shapes using layer-upon layer of metals, curable resins, ceramics, plastics, nanoparticles and other materials. 3D printers may also have a laser attachment for engraving the cast products. Studies have indicated that 3D printers are capable of generating potentially harmful concentrations of ultrafine particles and chemical vapors during the print process and through processes used following printing to treat the cast products. This program outlines the common types of 3D printers used at Longwood University, associated risks, and recommended health and safety practices, and proper disposal methods of hazardous materials.

SCOPE

This program applies to all faculty, staff, and students who conduct 3D printing in research and teaching laboratories, art and theater studios, shops, other academic spaces, and maker spaces. This program also applies to personal 3D printers used in Longwood University buildings.

ABBREVIATIONS

3D: Three-dimensional

ABS: Acrylonitrile Butadiene Styrene

EHS: Environmental Health and Safety

FDM: Fused Deposition Modeling

FFF: Fused Filament Fabrication

MJM: Multi-jet Modeling/Multi-jet Printing
MJP: Multi-jet Printing

OSHA: Occupational Health & Safety Administration

PLA: Polylactic Acid

PI: Principal Investigator

PPE: Personal Protective Equipment

SDS: Safety Data Sheet

SLA: Stereo lithography

SLS: Selective Laser Sintering

SOP: Standard Operating Procedure

UFP: Ultrafine Particles

UV: Ultraviolet

VOC: Volatile Organic Compounds

RESPONSABILITIES

Departmental Administrators

Department Administrators must ensure approval from Space Planning prior to placing a purchase order for new 3D printers. This will allow for the assessment of the printer, feedstock, and intended placement.

Retain inspection and maintenance records for ductless fume hoods utilized by their departments.

Environmental Health and Safety

The Longwood University 3D Printer Safety Program is administered by Environmental Health and Safety. EHS will function as a technical recourse to departments and will assist in carrying out their responsibilities. EHS is responsible for:

- Developing and maintaining the Longwood University 3D Printer Safety Program
- Developing and providing 3D Printer Safety Program Training
- Assess the effectiveness of this program
- Maintain an electronic chemical inventory program and SDS Database to make SDS's readily assessable for chemicals used in 3D Printers

Faculty and Staff

Prior to purchasing a 3D printer complete a Space Planning Request and get approval from the committee.

Faculty and Staff must adhere to this policy and train their students to operate 3D printers per the guidelines in this program and the manufacturer's instructions.

Faculty and Staff working with 3D printers must be trained in either Longwood University's Hazard Communications Program or Chemical Hygiene Plan, and the University's Hazardous Waste Plan.

Space Planning

Develops and carries out the campus-wide space management processes to effectively and efficiently utilize campus physical assets in support of the entire university community.

Space planning approves all space configurations and modifications changes. Depending on the project, there is a fee for project estimates. This fee increases as the complexity of the project increases.

COMMON TYPES OF 3D PRINTERS

Fused deposition modeling (FDM) printers melt a thermoplastic filament and deposit molten plastic in layers until the 3D model is complete. Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) plastics are the most commonly used in this process, though other filament materials are available. When heated during the print process, both media types produce large concentrations of ultrafine particles (UFP). Exposures to UFP or nanoparticles, particularly at high concentrations, have been associated with adverse health effects. Depending on the filament material, elevated concentrations of volatile organic compounds (VOC) can also be produced during the printing process.

Multi-jet modeling (MJM), also called multi-jet printing (MJP), is a printing process that deposits UV photo-curable plastic resin or casting wax layer-by-layer.

Selective laser sintering (SLS) is a type of stereo lithography where powdered metals are sintered (fused) together using lasers to form a solid structure. Some powdered metal printers use an adhesive rather than laser sintering to bond the metal powder.

Stereo lithography (SLA) employs a laser or ultraviolet (UV) light to cure photopolymer resins (usually thermoplastics) layer-by-layer into a prototype form built on a support that must be manually or chemically removed. Rapid prototyping SLA printers do not require a support allowing faster builds to occur.

RISKS AND SAFETY CONSIDERATION

Compressed gases: Inert gases (usually argon or nitrogen) are used to minimize contamination caused by reactive gases. Controls and exhaust ventilation are required to prevent low-oxygen environments.

Flammable and Reactive Dusts: SLS uses a laser to fuse powdered metals. Reactive and flammable metal powders such as aluminum and titanium are used to fabricate alloy tool and metal parts. Other metal powders can also be used, including stainless and nickel alloy steels. While particulate emissions from SLS printers are controlled inside a closed inert gas system (e.g. argon) during the print cycle, particulate emissions can occur during filling, leveling, staging, filter changes and clean-up. Safety precautions to prevent fires and explosions during SLS printing include:

- written standard operating procedures for proper handling and use of metal powders
- storing metal powders in cool, dry areas
- elimination of ignition sources
- static grounding of equipment and personnel
- system safety interlocks
- Class D fire extinguisher
- flame retardant clothing
- specialized wet HEPA vacuum
- meticulous housekeeping
- proper and timely waste disposal.

Physical hazards: 3D printers are relatively complex instruments, incorporating high-voltage power supplies, multiple moving parts, hot surfaces, high-powered lasers, welding processes and/or UV light that all pose risks if not addressed in printer design and operation. In most cases, printer manufacturers have devised engineering controls to prevent accidental exposures to physical hazards. Users must not attempt to defeat interlocks or other safety devices on 3D printers.

Printer substrates: Thermoplastics and photopolymers can be flammable and toxic, and plastic monomers can cause irritation and skin sensitivity.

Ultrafine particles: FDM and SLA printers produce particulate matter or particles having diameters less than 0.1 microns (um). The UFPs that are produced can penetrate and irritate the skin, lungs, nerves and brain tissues. Elevated UFP levels have been linked to adverse health effects including cardiopulmonary mortality, strokes and asthma. Users of 3D printers in poorly ventilated areas have reported eye, nose and throat irritation. MJM and SLS printers produce fewer ultrafine particulates during operation than other printers.

Volatile organic compounds: Studies by Steinle (2016) and Azimi et. al. (2016) reported a wide range of VOCs emitting from an FDM style printer known as a fused filament fabrication (FFF) printer. Researchers have identified more than 50 organic vapor emissions from FFF printers depending on the filament material and operating temperatures. VOC's emitted from ABS and PLA printers have been reported to cause headaches, respiratory irritation and eye irritation. MJM printers also emit VOCs during use. In a poorly ventilated room with multiple printers, VOCs could build to potentially hazardous levels.

PROCEDURES AND OTHER INFORMATION

Procurement

Only printers certified to the ANSI/CAN/UL 2904 Standard may be purchased. This standard tests and certifies printers for low emission rates.

Due to ventilation, filtering, or other safety requirements, all 3D Printers must be approved by Space Planning prior to purchase or relocation of existing 3D Printers.

Placement

The order of preference for printer placement is as follow:

1. Inside an operational chemical fume hood.
2. Adjacent to a slot hood, elephant trunk hood, or other direct exhaust method.
3. Within a ductless fume hood or 3D printer enclosure with HEPA and Activated Carbon filtered ventilation.
   Note: Ductless fume hoods require an annual inspection by a third-part contractor, as well as frequent changing of filters. This is an ongoing cost and is the responsibility of the user or department.

Resin printers have additional requirements. When a printer uses a liquid filament such as Acrylonitrile butadine styrene (ABS) or a printer system that utilizes a caustic bath, the area where the printer is located needs to have an eyewash station, safety shower and sink.

Installation

Industrial grade printers should be:

- Installed by the manufacture or manufacturer's representative
- Operated only by those trained by the manufacture or manufacturer's representative
- Serviced by those trained by the manufacture

Consumer grade printers should be installed per the manufacturer's instructions.

In either case, placement must happen in consultation with Environmental Health and Safety or the Cole Cook College of Arts and Sciences Safety Specialist.

3D Printing Precautions

Follow all safety recommendations established by the manufacturer. 3D printers must be installed, operated and maintained according to the manufacturer's instructions. Before purchasing a 3D printer, information regarding pollutant generation, emission rates, exposure controls and ventilation requirements should be requested and reviewed. Modified or novel use of 3D printers should be avoided without written approval of the manufacturer as well as EHS.

Establish rules for use. Departments, faculty, supervisors, or staff using 3D printers must establish guidelines and approvals for use. Users must express a valid reason for what they seek to create and demonstrate that they are not violating patent laws, are not producing weapons or other dangerous materials, and are capable of controlling the recognized hazards. The duration of equipment operation may also be considered for control.

Ensure proper ventilation and safety controls. Most 3D printers are not designed with exhaust ventilation or filtration provisions, therefore particulate, gas and vapor emissions can be problematic in poorly ventilated areas. Therefore, ensure that exhaust ventilation or filtration is operating correctly before using the 3D Printer.

Take precautions when using compressed gases. Metal 3D printers typically use argon, nitrogen or some other inert gas to create a noncombustible/non-explosive environment inside the printing chamber where particle welding or sintering takes place. During printer operation, the controlled flow and ventilation of these gases poses little hazard of asphyxiation or toxic exposure. However, should there be a leak in the system during maintenance checks or equipment malfunction, the possibility exists that these gases might collect in an enclosed printer chamber, floor pit, or other confined lab area creating an asphyxiation hazard. Inserting your head into one of these low oxygen environments, even for a few seconds, could cause a person to lose consciousness and potentially suffocate.

Register 3D printers with lasers and follow laser safety requirements. Class 1 - 4 lasers must be registered with EHS. Additional hazard controls for the laser may be necessary if the laser is not completely enclosed or if maintenance or service operations on the printer allow access to hazardous laser radiation not accessible during normal operation.

Maintain fire extinguishers in (or near) the 3D printing area. Contact EHS to ensure that proper fire extinguishers are available at the 3D printing location. Standard carbon dioxide (CO_2) and dry chemical extinguishers are appropriate for most ink jet, thermoplastic or photopolymer printers. Class D extinguishers must be available where flammable or reactive metal powders are used.

Get trained. All persons working with 3D printers must receive training on the chemical, physical and biological hazards associated with the equipment as well the standard operating procedures (SOPs) implemented to mitigate those hazards. Equipment manuals, online training modules, and SOPs should be retained for ongoing training instruction. Departments and faculty are responsible for ongoing safety and hazard communication training related to 3D printers. All training sessions (formal and informal) must be documented.

Review Safety Data Sheets (SDS). SDS for all materials used in a 3D printing process must be thoroughly reviewed prior to use. Contact EHS with any questions about hazards/risks or required controls, including personal protective equipment.

Wear personal protective equipment (PPE). An assessment should be made relative to the equipment, printer substrates, and procedures to determine the appropriate PPE. Follow any recommendations made by equipment manuals, SDS, or other hazard-specific documentation. Contact EHS for assistance as necessary. PPE for 3D printing may include, but is not necessarily limited to:

- **Eye protection** – safety glasses, goggles or face shields appropriate for the chemical hazards must be used, particularly when loading liquid monomer reservoirs or using caustic cleaners.
- **Gloves** – 3D processes may involve hot surfaces such as the print head block and UV lamp. Sharp or rough edges and pinch points may also be present. In additional to these physical hazards, resistance to irritant plastics and corrosive chemicals must also be considered when selecting glove(s) for 3D printing tasks.
- **Chemical-resistant lab coat (or apron)** – Lab coats, smocks or aprons should be worn when 3D printing or post-printing processes involve irritating or caustic chemicals. Selection is dependent on the materials and associated procedures.
- **Flame-retardant lab clothing** – Powdered metal printing with reactive metals or flammable polymers or monomers may present a fire or explosion risk. Flame-retardant gloves, lab coats, coveralls, head shrouds and face shields with appropriate static grounding may be needed.
- **Respirators** – Powdered metal printer manufacturers recommend using powered air purifying respirators with a flame retardant hood, particularly when loading, leveling, changing filters, extracting or cleaning that involves pyrophoric and reactive materials. If negative pressure respirators are worn, they must be suitable for the emissions generated and users must be fit tested and trained to ensure protection. All employees using respirators must be enrolled in the EHS respiratory protection program.

Operations

Always follow the manufacturer's instructions for operations. The following are general considerations:

- Utilize the recommended feedstock. Inexpensive, off-brand products are more likely to contain contaminants, producing an inferior result and possibly more harmful fumes.
- Keep the printer and area around it clean. The nozzle's cleanliness should be verified before use, and the build plate cleaned after use. Wipe with a wet cloth, or if vacuuming, ensure there is a HEPA filter to catch dust.
- Wash hands after cleaning or handling uncured products.
- When checking on a print sequence, note that a cloth face covering or N95 mask is not complete protection. They will absorb almost none of the VOCs and UFPs emitted. To provide protection, a fitted NIOSH respirator is necessary. These are expensive and require fit testing from a medical provider. Utilize remote monitoring when possible.
- The extruder nozzle temperature should be set to the lowest necessary to achieve the printing objective. Higher temperatures will produce unnecessary fumes and increase particulate emissions.
- 3D Printers on campus may not be used to produce weapons, weapon components, or drug paraphernalia.
- Do not modify the printer in any way that would void either the manufacturer's warrantee or any of the machine's certifications, such as its compliance with ANSI/CAN/UL 2904.
- After a print cycle, allow the nozzle to cool and fumes to dissipate before opening the printer to access the finished product.
- Wear eye protection when performing activities that can produce projectiles, such as cutting off extraneous material.

WASTE DISPOSAL

Several different waste streams may be generated during the 3D printing process. Containment, labeling, and disposal of 3D printing wastes are outlined below.

Metal Powders

- Metal powders collected in the 3D printer collection containers must be covered/passivated with dry quartz sand (or equivalent). Sand must be completely dried via an oven prior to passivation (removal of all water/moisture).The dry quartz sand must be introduced to the 3D printer system according to manufacturer's recommendation (consult specific 3D printer operations manual for instructions on how to passivate the metal powder).

- Place the lid on the metal powder collection container immediately following passivation. Secure the lid. Observe the lid and container for at least 48 hours to determine if there is any gas generated (bulging lid or container sides).
- Affix hazardous waste label to the container and fill out completely, including the specific metal powder collected.
- A specialized wet HEPA vacuum with an inerting fluid must be used to capture reactive metal powders during cleaning of metal 3D printers. Manufacturer's precautions for grounding, using and emptying this vacuum must be followed. To prevent fires and explosions, standard shop vacuums must never be used for cleaning reactive metal powders. Vacuumed materials are to be labeled and disposed as hazardous waste as described above.

Printer Cartridges

- Empty printer cartridges should be disposed of according to the manufacturer's instructions (cartridge recycling, hazardous waste, or regular trash).
- Empty printer cartridges that can be returned to the manufacturer should not be disposed as hazardous waste or in the regular trash. Recyclable cartridges must be empty prior to returning to the manufacturer. Original shipping boxes should be retained and used to return the cartridges whenever possible.
- Empty printer cartridges that cannot be returned to the manufacturer should be disposed in accordance with EHS recommendations.

Vacuum Filters

- 3D printer cartridge filter and/or fine filter (if present) should be removed from the recirculating filter system. Consult the safety procedures outlined in the manufacturer's operation manual; be sure to follow all personal protective equipment recommendations when removing filters.
- The cartridge filters and fine filters should be placed in a container and immediately passivated with dry quartz sand (void of all water/moisture content via oven drying) or mineral oil as per the manufacturer's recommendations.
- Place lid on filter collection container immediately following passivation. Secure the lid. Observe the lid and container for at least 48 hours to determine if there is any gas generated (bulging lid or container sides).
- Affix a hazardous waste label to the container and fill out completely, including the specific materials processed through the filters.

Base Bath Solutions

- Base bath solutions (e.g. sodium hydroxide, potassium hydroxide) used in the finishing steps of 3D printing process are to be collected as chemical waste when the solutions are spent or no longer utilized.
- Affix a hazardous waste label to the container(s) and fill out completely, including the full name of the chemical(s) used in the base bath solution.

COMPLIANCE REQUIREMENTS

Regulations and Standards

29 CFR 1910.132 OSHA Protective Equipment Standard

29 CFR 1910.134 OSHA Respiratory Protection Program

29 CFR 1910.1200 OSHA Hazard Communication Standard

Longwood University Policy and Procedures

Longwood University Environmental Protection Policy 2017

Longwood University Environmental, Occupational, Health and Safety Policy 2018

Longwood University Chemical Hygiene Plan

Longwood University Hazard Communications Plan

Longwood University Hazardous Waste Plan

Longwood University Personal Protective Equipment Program

Record Requirements

All the 3D printers need to be documented. This list is to include location, asset tag no., manufacture, serial no., and purchase date.

Printers within ductless hoods also need to have the hood's filter changes be logged. This includes which filters were changed and when, and when the filters need to be changed again. Inspection records are to be kept by the department's administrative assistant.

APPENDICES

Appendix A: 3D Printer Inventory

Appendix B: Ductless Fume Hood Maintenance and Filter Change Log

REFFERENCES

Parham Azimi, Dan Zhao, Claire Pouzet, Neil E. Crain and Brent Stephens (2016) Emissions of Ultrafine Particles and Volatile Organic Compounds from Commercially Available Desktop Three Dimensional Printers with Multiple Filaments, Environmental Science & Technology, an ACS Publication, DOI:10.1021/acs.est5b04983.

Patrick Steinle (2016) Characterization of emissions from a desktop 3D printer and indoor air measurements in office settings, Journal of Occupational and Environmental Hygiene, 13:2, 121-132, DOI: 10.1080/15459624.2015.1091957.

Revisions Review History

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