Three-Dimensional (3D) Printer Safety

University of Tennessee Safety Guide LS-023

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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, nanomaterials and other materials. 3D printers may also have a laser attachment for engraving the cast products which can pose specific hazards. 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 guidance outlines the common types of 3D printers used at the University of Tennessee, Knoxville (UTK), associated risks, and recommended health and safety practices, and proper disposal methods of hazardous materials.

Scope and Applicability

This guidance applies to all students, staff and faculty who conduct 3D printing in research and teaching laboratories, maker spaces, and academic shops at UTK.

Abbreviations and Definitions

Abbreviations

3D: Three-dimensional

ABS: Acrylonitrile Butadiene Styrene

EHS: Environmental Health and Safety

FDM: Fused Deposition Modeling

FFF: Fused Filament Fabrication

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

OSHA: Occupational Health & Safety Administration

PLA: Polylactic Acid

PI: Principal Investigator

PPE: Personal Protective Equipment

SDS: Safety Data Sheet

SLA: Stereolithography

SLS: Selective Laser Sintering

SOP: Standard Operating Procedure

UFP: Ultrafine Particles

UTK: University of Tennessee Knoxville (Main Campus)

UV: Ultraviolet

VOC: Volatile Organic Compounds

Definitions

None.

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 stereolithography where powdered metals are sintered (fused) together using Class 4 lasers to form a solid structure. Some powdered metal printers use an adhesive rather than laser sintering to bond the metal powder.
- **Stereolithography (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 Considerations

- **Biological hazards:** 3D printing has expanded into the medical field to include printing of biological materials, such as cells and frameworks for engineered tissue generation. Exposures to biohazardous aerosols, infectious agents or bloodborne pathogens must be assessed and mitigated.
- **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 class 4 laser to fuse powdered metals. Reactive and pyrophoric 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 and 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 UFPs 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. Many users of 3D printers in poorly ventilated areas have reported eye, nose and throat irritation. MJM and SLS printers produce less 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.

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 expressed, written approval of the manufacturer as well as UTK EHS.
- **Establish rules for use.** Departments, principal investigators (PIs), supervisors, or course instructors 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, areas where plastics, reactive metals and toxic support materials are used must be well ventilated. A *minimum* of 4 air exchanges/hour is required to prevent occupant irritation and the risk of fire or explosion; however an increased air exchange rate may be necessary depending on the number of printers and/or operating frequency and duration (as determined by risk assessment). Whenever possible, manufacturer exhaust ventilation and/or filtration kits, chemical fume hoods, or other local exhaust systems should be used to control hazardous emissions. Additionally,

areas where unreacted printing materials are handled or cured, and/or where caustic (corrosive) support material is cleaned or removed, must be similarly ventilated to control hazardous emissions. An eyewash is required in areas where caustic chemicals are used.

- **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. Therefore, all confined spaces in a 3D printing area should be identified and labeled. Additional safety precautions must be taken whenever a gas leak or build-up is suspected in an enclosed area, including but not limited to, opening doors, ports, panels, etc. and allowing them to vent for several minutes before entering. If appropriate, fans or blowers can be used to accelerate the venting process. Contact UTK EHS at ehs_labsafety@utk.edu or 865-974-5084 for assistance in identifying and labeling confined spaces.
- **Register 3D printers with class 3B or 4 lasers and follow laser safety requirements.** Class 3B or Class 4 laser must be registered with UTK EHS according to the instructions provided at https://radiationsafety.utk.edu/lasers/. Additional hazard controls for the laser may be necessary if the laser is not completely enclosed, or if maintenance or service operations of the printer present 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. A manufacturer's representative should provide this training or the required hazard information upon procuring the equipment. Future users of the equipment must be trained by experienced users. Equipment manuals, online training modules, and SOPs should be retained for ongoing training instruction. Departments and PI's 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 (see below).
- **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 UTK 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 UTK EHS respiratory protection program.

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 (void 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 a UTK hazardous waste label to the container and fill out completely, including the specific metal powder collected, and submit to UTK EHS as soon as possible.
  - 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 through as hazardous waste or disposed 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 UTK 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 UTK hazardous waste label to the container and fill out completely, including the specific materials processed through the filters, and submit to UTK EHS as soon as possible.

- **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 UTK 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, and submit to UTK EHS as soon as possible.

References

Regulations and Standards

29 CFR 1910.132 OSHA Personal Protective Equipment Standard

29 CFR 1910.134 OSHA Respiratory Protection Standard

29 CFR 1910.1200 OSHA Hazard Communication Standard

UT Policy

UT System Safety Policy SA0100 – Safety and Environmental Health Program

UTK Programs, Procedures, Plans, and Guides

UTK Hazardous Waste Management Plan – EC-001

UTK Laboratory Health & Safety Program – LS-001

UTK Local Exhaust Ventilation Guide – IH-001

Published Literature

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.

Appendices

None.

Disclaimer

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