GUIDELINES FOR 3D PRINTERS

3D printing is an additive process molding virtual objects or digital images into 3-dimensional shapes using layer upon layer of metals, curable resins, ceramics, plastics, nanomaterials and other materials. 3D printers may have a laser attachment for engraving that presents additional hazards. The objective of this guideline is to establish health and safety requirements for using 3D printers in University of Pittsburgh facilities. The guideline is presented in recognition of the continued expansion of 3D printer use by faculty, staff and students. Studies have indicated that 3D printers are capable of generating potentially harmful concentrations of ultrafine particles (UFP) and chemical vapors during the print process and through processes used following printing to treat the finished product. This guideline establishes the minimum requirements necessary for safe use of 3D printers at Pitt.

1. Common Types of 3D Printers

1.1. Fused deposition modeling (FDM) – These printers melt a thermoplastic filament depositing the melted plastic in layers until it fills up a model. Acrylonitrile Butadiene Styrene (ABS) and Polyactic Acid (PLA) plastics are commonly used in this process, but 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. Elevated concentrations of volatile organic compounds (VOC) can also be produced during the printing process.

1.2. Steriolithography (SLA) - These machines use 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.

1.3. Selective laser sintering (SLS) - A type of steriolithography 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.

1.4. Multi-jet modeling (MJM) – Also called Multi-Jet Printing (MJP) is a printing process that deposits UV photo-curable plastic resin or casting wax materials layer by layer.

2. Risks and Safety Considerations

2.1. 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 and other safety devices on 3D printers.

2.2. Airborne emissions

Two research studies 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 dependent on the filament material used and printer 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.

2.3. Chemical and health hazards

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. Rooms with 3D printers should have at least 6 Air Changes per Hour.

2.3.1. Ultrafine particulates (UFPs) – Fused deposition modeling (FDM) and Steriolithography (SLA) printers are producers of ultra-fine particulates 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 cardio-pulmonary 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.

2.3.2.Flammable and Reactive Dusts - Selective laser sintering (SLS) uses a class 4 laser to fuse powdered metals under an argon blanket. 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 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:

- meticulous housekeeping,
- proper handling of metal powders,
- cool dry powder storage,
- static grounding of equipment and personnel,
- flame retardant clothing,
- elimination of ignition sources,
- specialized wet HEPA vacuums,
- system interlocks,

- Class D fire extinguishers,
- proper waste disposal, and
- documented SOPs.

2.4. Argon gas controls and exhaust venting are required to prevent inert atmosphere accidents.

2.5. Thermoplastics and photopolymers can be flammable and toxic, and plastic monomers can cause irritation and skin sensitivity.

3. Biological Materials

3D printing has expanded into the medical field to include printing of biological materials, such as cells and frameworks for engineered tissue generation. Potential exposures to biohazardous aerosols, infectious agents or bloodborne pathogens must be considered.

4. 3D Printing Precautions

4.1. Manufacturer's Safety Recommendations – 3D printers must be installed, operated and maintained according to the manufacturer's instructions. Researchers and print owners should demand full disclosure for pollutant generation, emission rates, exposure controls and ventilation requirements before purchasing the equipment. Modified or novel use of 3D printers should be avoided without expressed, written approval of the manufacturer.

4.1.1. Training – All persons working with 3D printers must receive specific training on the chemical, physical and biological hazards associated with the equipment. 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 and online training modules 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.

4.1.2. Safety Data Sheets – Safety data sheets for all materials used in a 3D printing process should be closely scrutinized prior to use.

4.1.3. Controlled use rules – Departments and PI's 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 controlling the recognized hazards. The duration of equipment operation may also be considered for control.

4.1.4. Placement and required ventilation – Areas where plastics, reactive metals and toxic support materials are used must be well ventilated to prevent occupant irritation and the risk of fire or explosion. Six to ten air changes per hour are required for areas housing 3D printers. Chemical fume hoods and local exhaust systems can also be used to control hazardous fugitive emissions. If the manufacturer of the 3D printing equipment offers exhaust ventilation kits or options, they must be strongly considered unless other engineering controls are identified to control emissions. Areas where unreacted printing materials are handled or cured, and/or where caustic support material is cleaned or removed shall also be ventilated to control hazardous emissions.

4.1.5. 3D metal printers - Typically use argon, nitrogen or some other inert gas to create a non-combustible/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 become unconscious or worse. While a remote possibility, all confined spaces in a 3D printing area should be identified and labeled. Added precautions should be taken whenever a gas leak or build-up is suspected in an enclosed area. The hazard can be greatly diminished by opening these confined and allowing them to vent for several minutes before entering. Fans or blowers can be used to accelerate the venting process. Contact EH&S (412-624-9505) should you have any questions about identifying and labeling confined spaces.

4.1.6. Fire Extinguishers - EH&S should be contacted to assure that proper fire extinguishers for use by trained professionals are available at the 3D printing location. Standard CO2 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.

5. Personal Protective Equipment (PPE)

Depending on the 3D printing process, the support material and removal processes, and all associated chemicals and materials, the following personal protective equipment must be considered. Required PPE for each specific 3D printer must be documented.

5.1.1.1. 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.

5.1.1.2. Gloves – 3D processes may involve hot surfaces such as the print head block and UV lamp. Sharp or rough edges, pinch points, may also be involved. In additional to these physical hazards, irritating plastics, corrosive chemicals chemical resistance must also be considered when selecting glove(s) for 3D printing tasks.

5.1.1.3. Flame Retardant (FR) lab clothing – Powdered metal printing with reactive metals or flammable polymers or monomers may present a fire or explosion risk. FR gloves, lab coats, coveralls, head shrouds and face shields with appropriate static grounding may be needed.

5.1.1.4. Respirators – Powdered metal printer manufacturers recommend using powered air purifying respirators (PAPRs) with an FR 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 should be fit tested to assure protection.

6. Waste Disposal

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

6.1.1.Metal powders collected in the 3D printer collection containers must be covered/passivated with dry quartz sand. 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).

6.1.2. Sand must be completely dried via an oven prior to passivation (void of all water/moisture).

6.1.3. 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).

6.1.4. University waste chemical label must be affixed to the container. Label should be filled out completely and include the specific metal powder collected.

6.1.5. A specialized wet HEPA vacuum with an inerting fluid must be used to capture reactive metal powders during cleaning of the Electro Optical System(EOS) and similar 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.

7. Vacuum filters

7.1.1. If the 3D printer system has a cartridge filter and/or fine filter, these filters 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.

7.1.2. 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 (if recommended by the manufacturer's operation manual).

7.1.3. 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).

7.1.4. University waste chemical label must be affixed to the container. Label should be filled out completely and include the specific metal powder that was processed through the filters.

7.2. Printer cartridges

7.2.1. Empty printer cartridges should be returned to the manufacturer via their 3D printer cartridge recycling program center.

7.2.2. The cartridges must be empty prior to returning to the manufacturer.

7.2.3. Original shipping boxes should be maintained in order to return the cartridges.

7.2.4. Empty printer cartridges that can be returned to the manufacturer should not be disposed through the University's Chemical Waste Program or disposed in the regular trash.

7.3. Base bath solutions

7.3.1. Base bath solutions (e.g. sodium hydroxide, potassium hydroxide) used in the finishing steps of 3D printing process should be collected as chemical waste when the solutions are spent or no longer utilized.

7.3.2. University waste chemical label must be affixed to the container. Label should be filled out completely and include the chemical name of the base bath solution.

8. 3D Printers containing lasers

8.1. Any 3D printer that contains a high-powered Class 3B or Class 4 laser must be registered with EH&S. Visit the Laser Section of the Lab Safety web page for instructions to register a laser.

8.2. If the laser on the printer is not completely enclosed, the room must be secured during operation and all individuals located within the space must wear approved laser safety eye protection. A laser in use sign should also be posted on the door to the space.

9. Summary of Safety Provisions for 3D Printing

- Always follow manufacturer's guidelines.
- Know the hazards before printing. Contact the manufacturer or EH&S (412-624-9505) if you have questions about safe printer operations, ventilation, PPE or waste disposal.
- Assure adequate ventilation when selecting a 3D printer location.
- Document and require PPE appropriate for hazards as recommended by the manufacturer (or EH&S).
- Once printing has started, never open the printer or defeat interlocks.
- Uncured printing material may be hazardous. Avoid direct splash and skin contact.
- In case of a spill, absorb liquids. Wipe or HEPA vacuum reactive powders. Package clean-up material for chemical waste disposal.
- Call the campus emergency number 412-624-2121 for any emergency support. For fires, pull the nearest fire alarm and evacuate the area. Remain available to inform emergency responders of the potential hazards.

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 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