1. Introduction

3D printing, or additive manufacturing, is the construction of three-dimensional objects from computer-aided design (CAD) models or digital 3D models (1) (2). The development and use of 3D printing technologies is growing rapidly in academia, commercial, and consumer sectors. At Kennesaw State University (KSU), 3D printers are being used by students and researchers across the university from makerspaces to research laboratories. While recognizing the valuable role of 3D printing technologies to the teaching and research endeavors of the university, the increasing use of 3D printing technologies on campus requires thoughtful and proactive standards and procedures to support a healthy and safe environment within which to use these technologies.

KSU is committed to ensuring a safe and healthy learning, teaching, and working environment for students, faculty, and staff. Toward this end, Colleges and departments must ensure appropriate safety measures are taken when implementing 3D printing operations to minimize the associated hazards and risks.

2. Purpose

This guidelines document describes the general requirements and best practices for proper installation and safe operation of 3D printers on KSU properties.

3. Scope

These guidelines apply to the installation and use of all 3D printers by faculty, staff, and students on all properties leased, owned, and operated by KSU.

4. Roles and Responsibilities

A. Department Administration

- Set performance expectations, manage laboratory safety risks, and ensure the department adheres to these guidelines and other environmental and occupational safety laws, regulations, and policies.
- Coordinate with Maintenance and Operations (M&O), Design and Construction (D&C), and the Environmental Health and Safety (EHS) Department when planning the purchase and installation of new equipment.
- Ensure that the affected department's personnel and students have received the appropriate safety training on the safe use of 3D printers.
- Ensure prompt reporting and appropriate investigations of incidents involving 3D printers.
- Agree upon regular inspections and maintenance with M&O or discuss the need for 3rd party maintenance and service contracts.

B. Faculty, Staff, and Students

- Understand and comply with the requirements of these guidelines.
- Complete all required safety training as assigned.
- Operate 3D printers only for intended purpose and as per manufacturer's instructions.
- Inform their supervisor/manager of the space (faculty or staff) of any problems, defective equipment or hazard relating to 3D Printers and associated equipment.

C. Facilities Design and Maintenance

- Ensure appropriate planning and design of 3D printing laboratories.
- Maintain building system necessary to ensure safety including ventilation systems.

D. Environmental Health and Safety (EHS)

- Develop safety guidelines for 3D printing and revise them as needed.
- Conduct hazard assessments of the existing and the proposed processes and advise colleges and departments on the appropriate safety control measures.
- Develop and provide training on the safe use and operation of 3D printers.
- Conduct routine inspections to ensure the proper use and operation of 3D printers.
- Conduct air quality assessments in 3D printing shops and laboratories.

5. Definitions

- $PM_{2.5}$ - fine particles with aerodynamic diameters of <2.5 µm.
- Ultra-Fine Particles (UFP) – Particles with an aerodynamic diameter of ≤100 nm.
- Volatile Organic Compounds (VOCs) - organic compounds that have a high vapor pressure at room temperature that are emitted into the air from products or processes.

6. Health and Safety Concerns

3D printing technology has several potential health and safety hazards that should be taken into consideration when planning new 3D printing operations. The potential hazards vary widely depending on the technology, printer brand and the materials being used (4)(5). There are several types of technologies and a variety of materials that are currently used in 3D printing. The current technologies can be grouped into seven categories - binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, vat photopolymerization, and sheet lamination (4). Available 3D printing materials include acrylonitrile butadiene styrene (ABS), acrylonitrile styrene acrylate (ASA), polylactic acid (PLA), high-impact polystyrene (HIPS), polyamides (PA), poly vinyl alcohol (PVA, and carbon nanotubes (4). Printer parameters such as the nozzle temperature, build plate temperature, filament feed rate, and the number of printers can all influence emissions (4). Below is a description of key hazards associated with 3D printing.

A. Exposure to fine Particulates and Volatile Organic Compounds

Numerous research studies have shown that 3D printing processes emit UFP and VOCs. The particles and/or the VOCs emitted or generated can be inhaled by KSU students and personnel working with the technology, which can cause adverse health effects.

1. Exposure to Fine and Ultra Fine Particulates

Inhaled fine and ultra-fine particles have been linked to a variety of toxic effects, including increased oxidative stress, inflammation, cardiovascular effects, and cytotoxicity. Due to their size, UFPs can penetrate deep into the alveolar regions of the lung when inhaled and can cross into the blood stream, causing damage to remote organs (3) (4) (5). Indoor air modeling has shown that particles emitted from 3D printers present a greater health concern than ambient fine particles in poorly ventilated or confined spaces.

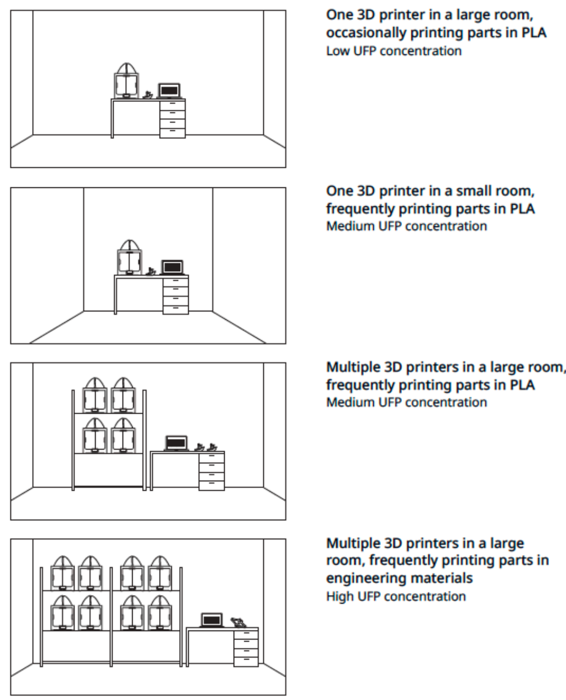


Figure 1: UFP Exposure Scenarios. (image courtesy of Ultimaker)

2. Exposure to Volatile Organic Compounds

A variety of VOCs are emitted during 3D printing processes (2) (3). The VOC may include odorants, irritants, and carcinogens. Different printing materials lead to different VOC species and yields (2) (3). Over 200 individual VOCs have been identified from 3D printer emissions. Compounds such as formaldehyde, styrene, methylene chloride, acetaldehyde and ethylbenzene that are either confirmed or suspected human carcinogens are commonly present in emissions from ABS, PLA and nylon filaments. ABS and Nylon filaments are likely to emit more VOCs than HIPS and PLA filaments (6). According to Chemical Insights, an institute of Underwriters Laboratories, and Georgia Institute of Technology, PLA filaments have produced over 50 identified VOCs, including 1-Butanol which can affect the eyes, skin, respiratory and central nervous systems. However, PLA has a considerably lower emission rate than its counterparts.

The VOCs released during 3D printing could exceed the occupational exposure limits or recommended indoor levels (3). Cases of occupational diseases associated with 3D printing have been reported, including work-related asthma and contact dermatitis (3). Numerous building and operating conditions including ventilation rates, air mixing, number of printers operating, and printer/filament combinations could affect the exposure concentrations (6). According to Ultimaker, one of the leading manufacturers of 3D printers, there are seven factors that affects the impact of 3D printing on the indoor air quality (7):

1. The room's dimensional volume.
2. The room's air exchange rate.
3. Number of 3D printers in use at the same time.
4. The item being printed.
5. Printing duration.
6. How close you sit to the 3D printer(s).
7. Other emission sources in the room.

3. Chemical Hazards

In addition to UFP and VOCs exposure, 3D printing can also emits numerous compounds such as polycyclic aromatic hydrocarbons (PAHs), phthalates, ozone, metal, or metalloid dusts (3). For instance, some of the metal powders used by metal 3D printing can be highly toxic. The thermoplastics used for 3D printing can cause irritation and skin sensitivity. In addition, the chemicals used to dissolve the support material or clean machine such as sodium hydroxide, or isopropanol are caustic or flammable.

B. Physical Hazards

Fire Hazard: 3D printers use high temperatures to melt materials, which can pose a fire risk if the printer malfunctions or if the material ignites. Several incidents involving 3D printer fires have been documented.

Explosion hazard: Finely powdered metals such as titanium and aluminum used in metal 3D printing are combustible and/or reactive and can cause fire or explosion. Such powder must be handled carefully including using specialized equipment.

Thermal hazards: The heated bed and extruder of a 3D printer can reach high temperatures. For instance, extrusion temperature can range between $100^{\circ}C$ and $500^{\circ}C$, depending on the material type (6). Such temperatures can result in thermal burns if the printer is not handled properly.

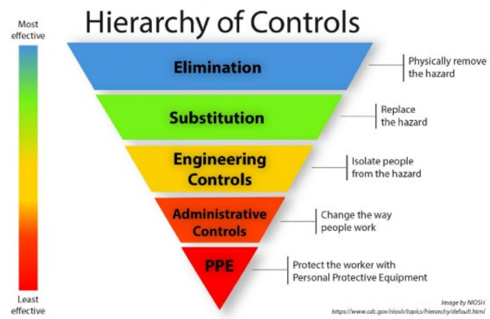
Electrical hazards: 3D printers use electricity to power the heating elements, laser, and motors. If the printer is not properly grounded or if there is a malfunction, it can pose a risk of electrical shock.

Laser Hazard: Some 3D printers use lasers for various functions, including leveling the print bed or melding the print materials. The power of the lasers varies from low power (Class 2) to high power (Class 3B or Class 4). While high power lasers may be safeguarded by safety interlocks within the design of the 3D printer during normal operation, the laser may pose a risk during maintenance of the device or if the safety interlocks are intentionally defeated.

Hand Tools: Tools with sharp edges (e.g., scrapers, razors, scalpels, etc.) that are sometimes used to separate 3D prints from their support material pose the risk of cuts, lacerations, and abrasions, if not properly handled.

7. Control Measures

Effective control of the hazards associated with 3D printing requires an integrated approach, which utilizes a mix of strategies. These include purchasing decisions, facilities design, operation, and use of personal protective equipment (PPE), based on the hierarchy of control method which ranks controls from most effective to the least effective control. When using this method, the feasibility of the most effective control should be explored first, before moving onto the less effective methods.



A. Purchasing Controls (Elimination/Substitution)

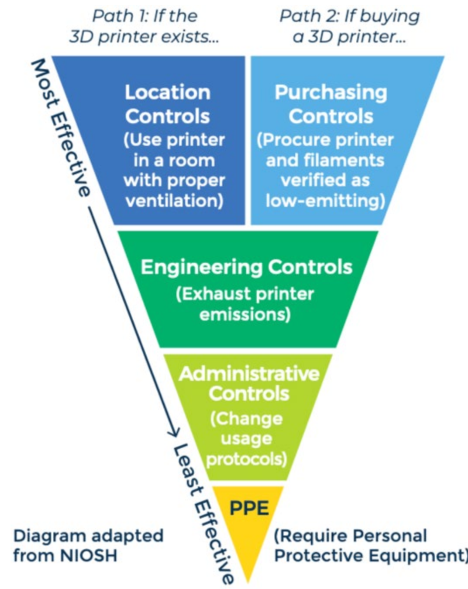


Figure 2: Hierarchy of Controls (image courtesy of Chemical Insights)

Emissions from 3D printers vary significantly based on both the printer type and the 3D printing material being used. Selecting the appropriate 3D printers and printing materials is therefore a critical 1st step. The following considerations should be made when purchasing 3D printers and printing materials:

- Colleges and departments should purchase 3D printers that have been certified to meet the ANSI/CAN/UL 2904 standard which establishes emission limits and testing protocols for 3D printers and recommended filaments. The verification for compliance with the standard may be done by the manufacturer or certified by a 3rd party.
- Select printers with integrated filtration systems, local exhaust, or an enclosure.
- Because PLA filament has been documented to produce less emissions compared to other common material, printers using PLA should be the primary choice. Use of other material will require EHS review and approval.
- Only purchase and use filament brands specified by the printer manufacturer for a particular printer.

1. Prior-Approval Process

- To ensure appropriate hazard and risk assessment in accordance with KSU's procedure for [Managing Environmental and Occupational Safety Risks and Impacts], colleges and departments must seek prior approval before purchasing 3D printers and certain print materials. Prior approval should be requested by completing and submitting the [Equipment Purchase Safety and Facilities Review Request Form].
- Upon receipt of the prior approval request, EHS will conduct an assessment to evaluate the potential hazards and provide a written report with the appropriate recommendations. **If the hazard assessment determines that certain facilities modifications such as ventilation improvement are required, a Facilities Project Request will need to be submitted to Design and Construction Services**.
- All required safety controls should be implemented **prior** to placing the 3D printer into operation.

B. Facilities Controls (Engineering Controls)

Selected locations of 3D printers have direct impacts on potential exposure to users and other building occupants. The following considerations should be made when selecting the locations of 3D printers.

- 3D printer rooms should have adequate and effective ventilation. Facilities where multiple printers will be used such as 3D printing farms/shops or makerspaces, could be considered laboratory or process spaces. The general ventilation of such facilities should provide outside air and exhaust with at least six (6) air changes per hour (ACH). The exhaust air should not be recirculated to the rest of the building.
- The ventilation rates of offices, libraries, conference rooms or residential rooms are not sufficient to remove constant emissions from the 3D printers. Multiple 3D printers should therefore not be placed in such spaces.
- Depending on the manufacturer's specifications and or the type of materials being used, such as ABS filament, local exhaust ventilation and/or enclosures may be required. This can be achieved by direct exhaust to the outside or by use of a portable filtration system (fume extractor). After conducting a hazard/risk assessment, EHS will work with the College/Department and Facilities to identify and implement the most feasible solution depending on the operation and the space.
- Printers and auxiliary equipment should be installed strictly according to the manufacturer's instructions. The selected location should ensure that sufficient access and working space is maintained to permit safe operation and maintenance of the printers.
- Printers should never be operated when the building HVAC system is not operational. Departments should consult with Facilities Maintenance to ensure that the HVAC system serving the printing room does not automatically shut down during certain operating hours.
- Appropriate emergency equipment, such as an eyewash or safety shower must be available where hazardous chemicals are used.
- Metal 3D printers present unique hazards associated with working with toxic and potentially reactive metal powders. Therefore, **metal 3D printing should only be conducted in a space that has specifically been designed for this purpose**.
- Because of the associated risk of fire, 3D printers should be in spaces equipped with automatic sprinklers. Portable fire extinguisher should be provided. A clean agent extinguisher such as CO_2 fire extinguishers is recommended for electronic equipment.

C. Operational Controls

- Printers should be strictly operated in accordance with the manufacturer's operating instructions and industry best practices. A printer should never be used in a manner that it is not intended for.
- Only material specified or approved by the manufacturer should be used. This includes filament and tapes/glue used on the base plate.
- Print using ONLY the printing materials approved for a particular shop/lab. Use of other material will require reassessment and approval from EHS.
- Given the documented impact of high nozzle and baseplate temperature on the emission rate, nozzle and base plate temperatures should be set at the lowest recommended settings that produces the required print quality.

- The printer nozzle should be cleaned before each use to remove filament residues left on the nozzle after printing to minimize emission from thermal degradation of the residue. Any filament, glue or tape residue left on the base plate should also be cleaned after each use. Follow the manufacturer's pre-print and post-print inspections and maintenance instructions, including on the selection of cleaning product and the appropriate cleaning process.
- Safety data sheets (SDSs) associated with any hazardous chemicals used in the 3D printing process must be provided to the end-user prior to use.
- Containers of powdered metals must be sealed tightly and kept in a secure location.
- Hazardous chemicals must be stored properly and labeled with the full chemical name and hazard. Chemicals containers should be kept closed while not in use.
- Operators and observers should maintain a safe distance from 3D printers while in operation to minimize exposure to printer emissions. Cameras can be used as a tool to facilitate remote observation.
- Access to 3D printing should be limited to authorized users. Printers should be operated when the space is least occupied.
- All individuals who will use 3D printers must be trained in the proper operation and care of the devices.
- 3D printers should not be left operating unattended unless the printer has a Declaration of Safe Unattended Use.
- 3D printer's safety interlocks must never be overridden or defeated.
- Flammable materials must not be used near 3D printers when operating or while still hot. The hot surfaces could provide a source of ignition.
- Work surfaces around and near the printer should be cleaned frequently with a wet cloth while floor and other surfaces should be HEPA vacuumed to remove particulates settled on the surfaces. Special vacuum cleaners are required when working with metal powders. The College/Department should ensure that the appropriate vacuum cleaner is available for vacuuming metal powers.
- No eating or drinking is allowed in 3D printing spaces.
- Users should wash hands frequently to avoid hand-to-mouth transfer of contaminants.
- The laboratory supervisor should develop and implement standard operating procedure (SOP) that includes start-up, normal operation, and emergency procedures. Supervisors should also develop specific procedures for handling and storage of chemicals/metal powders, cleaning, and waste management.

A. Personal Protective Equipment

To protect against the various chemical and physical hazards, use of appropriate certain PPE may be required depending on the task. Please review the following chart for PPE that may be required.

Body and hand protection	• Wear the appropriate chemical resistant gloves, laboratory coat or apron when working with hazardous chemicals such as flammable solvents, corrosive materials used for curing or rinsing prints, or uncured prints. • Use flame-resistant coveralls, gloves, and closed toe shoes when working with metal powder or other highly flammable materials. • Heat resistant gloves should be used for touching or handling hot objects. • Cut resistant gloves are recommended when using scrapers, razors, or scalpels to separate prints from support materials.
Eye/Face protection	• Use appropriate eye/face protection depending on the task. At minimum, safety glasses should be worn in the 3D print laboratory.
Respiratory Protection	• Use of the appropriate respiratory protection is required when working with metal powders, or when determined to be necessary following hazard/risk assessment by EHS. • Face filtering masks such as N95s do not provide protection against VOCs emitted by 3D printers and may not be effective against UFP. Therefore, they should not be used as a means of respiratory protection against 3D print emissions. • If respiratory protection is required, personnel expected to use respirator must be medically evaluated and cleared to use respirator and fit-tested, if necessary, in accordance with the University's Respiratory Protection Program.
Required PPE should be made readily available, and its use strictly and consistently enforced by the shop supervisor and/or the faculty member in-charge.	

8. Waste Disposal

The 3D printing process can produce several forms of hazardous waste that must be disposed of in accordance with Federal and State regulations and the KSU's Hazardous Waste Program. All hazardous wase must be disposed of through EHS.

- Chemical waste such as used solvents, corrosive liquids, contaminated wipes or empty canisters should be placed in appropriate containers and labeled. A waste pick-up request should be submitted in Chematix when ready for pick up. Waste containers should be kept tightly closed while not in use and in a secure location. Certain waste from metal 3D printers may require special handling.
- All disposable sharps (i.e., razor blades, scalpels, etc.) must be disposed in a hard-walled sharps container.
- **Contact EHS** for assistance on proper disposal of hazardous waste.

9. Emergency Procedures and Incident Reporting

- Any chemical spill should be cleaned up immediately. Only individuals who are trained and are comfortable with cleaning up spills should attempt to do so, and only if it can be done without causing personal injury or injury to others. Otherwise contact EHS at (470) 578-3321 or the campus emergency number (470) 578-6666 for assistance.
- Powdered metal spills should **not be swept or wiped but rather should** be **vacuumed** with the appropriate vacuum **machine** for metal powder.
- Only Class D fire extinguisher should be used with fire involving metals.

10. Incident Reporting

All incidents, including near misses, involving the 3D printing operation should be promptly reported in accordance with the University's Incident Reporting and Investigation procedures.

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