**Penn State EH&S – 3D Printing Health & Safety Guide**

***What is 3D printing?***

Three-dimensional “(3D) printing” is a burgeoning technology which involves creating three-dimensional objects by laying down successive layers of materials, which may differ in composition. Initially, a virtual design is created and stored by computer-aided design (CAD) with 3D modeling software, and/or by using a 3D scanner/device. Once a design model (file) is created, a 3D printer/printing application will print the image by laying down definitive, discreet layers, to create the object, layer-by-layer. Images may be simple, with one type of material, or highly complex with different integrated materials.

3D scanners employ one of several technologies, with more common technologies including: “time-of-flight”, “structured/ modulated light”, and volumetric scanning.

**3D Printing Applications**

3D printing applications are being developed for use in diverse industries, such as: medical/prosthetics, “bio-printing”, aerospace and aviation, foods, and automotive. 3D printing can be useful in any industry where *rapid prototyping* and subsequent rapid manufacturing are desirable. Personal 3D printers are now becoming readily available for home use and hobbyists.

***Why is 3D printing of significant interest at Penn State?***

As a research and educational institution, Penn State is not only involved in developing technologies, but in employing new technologies supporting Penn State academic programs. 3D printing technology is of interest to Penn State through academic and research applications in such fields as: learning technologies, visual arts, material sciences, life sciences, and various fields of engineering. One example of recent applications includes developing composite materials for use in the fields of biological/life sciences, and medicine.

***What are the main hazards associated with 3D printing?***

The hazards associated with 3D printing are related to the processes and technologies applied. These may range from: hazards associated with electrical/shock, electromechanical force, burns from molten materials, ultraviolet light (UV)/ laser beams, and to health hazards associated with inhalation of ultrafine and/or toxic smoke, fumes and dusts*.* *When installing 3D printers, various hazards should be considered for each type technology/application, and the specific work environment where installed.*

**3D Processes & Technologies**

Various technologies and processes are used to produce the layers in a 3D printed object. The American Society for Testing and Materials [(ASTM) Committee F42](https://www.astm.org/COMMIT/F42Brochure_Sept2015.pdf) is established to define standards in “Additive Manufacturing” (broad term to describe 3D printing).[[1]](#footnote-1) This group has classified additive manufacturing processes into seven categories including:

* **Vat Photo-polymerization** – containerized photo polymer resins are hardened using ultra-violet light source. Specific subcategories include: ***stereolithography (SLA), continuous interface production (CLIP), film transfer imaging, and solid ground curing***.
* **Material Jetting** – material droplets are applied through a small diameter nozzle (similar to inkjet printing), except layer-by-layer, then hardened by UV light.
* **Binder Jetting** – powder base material and liquid binder (gluing agent) are applied in a “build chamber.” Remaining powder can be removed and re-used.

* **Material Extrusion** – most commonly delivers plastic filament or metal wire to a heated nozzle which can move in a multi-planar fashion through computer-aided manufacturing software, to deposit the material layers. Filament materials often include: acrylonitrile butadiene styrene (ABS) resin, or polylactic acid (PLA), though various other materials may be used.
* **Powder Bed Fusion** – most common technology for this process is “***selective laser sintering***” which uses a high power laser to fuse small particles of plastic, metal, ceramic or glass powders to form a three-dimensional shape. The laser selectively fuses the powdered materials in cross sectional layers, layer-by-layer until the object is completed. Untouched powders in the process serve as the support structure.
* **Sheet Lamination** –Sheet materials are bound together with external force. Metal sheets are welded by ultrasonic welding, then milled into shape via CNC (computer numerical controlled) device. Paper sheets can be used with adhesive layers, and cut with precision blades.
* **Directed Energy Deposition** – Predominantly used in high-tech metal industry and rapid manufacturing applications. Similar to electron beam or plasma arc welding, the 3D printing apparatus is attached to a multi-axis robotic arm with a nozzle that deposits metal powder or wire onto a surface, subsequently melted by energy source (electron beam, laser, plasma arc), to form solid object.

***What are some specific hazards associated with 3D printing processes?***

**Health Hazards**

**Inhalation and related systemic exposure to hazardous agents** – Many 3D printing processes use thermoplastics and other materials, which are heated, extruded, and/or

fused using high energy sources. These processes emit ultrafine particle clouds and fumes in the nanoparticle range, (i.e. 1/10,000 millimeter or sub-micron range). For example, 3D printing via material extrusion using polylactic acid (PLA) feedstocks, using relatively low-temperature desktop applications can generate in excess of 20 billion particles per minute. Higher temperature acrylonitrile butadiene styrene (ABS) feedstocks can release in excess of 200 billion particles per minute. Nanoparticles are of concern because they are very small, have large surface areas (low density) and can readily penetrate, interact with, and/or traverse the body’s systems (i.e. skin, lungs, nervous and brain tissues) at the cellular level. Exposure to high concentrations of nanoparticles has been associated with adverse health effects, including: cardio-pulmonary and respiratory effects, cancer, asthma, and nervous system effects.[[2]](#footnote-2),[[3]](#footnote-3),[[4]](#footnote-4) Though PLA feedstocks are intended to be non-toxic and compatible with biological tissues, there may be unknown effects at very high concentrations, particularly in poorly ventilated spaces. The thermal decomposition products of ABS feedstock have been shown to have toxic effects on lab rodents. These hazards may be significant, thus installation designs must consider the adequacy of exhaust ventilation or filtration.

*Consult Penn State EH&S, and/or Office of Physical Plant Engineering Services for assistance and support in determining acceptable exhaust ventilation or filtration for a specific application.*

**Skin or respiratory sensitizers** – Certain thermoplastics and photopolymers (used in 3D printing) when activated by heat or UV light may contain toxic or hazardous monomers such as acrylates, or other sensitizing agents. U/V light may also pose a radiation hazard to the eyes or skin.

**Biological material hazards** – Life and/or Material Science applications involving biological materials, such as use of cells for engineered tissue generation, may expose

persons to aerosols containing biological materials or bio-hazardous agents. Appropriate biosafety and other engineering controls must be considered. *Consult Penn State EH&S for assistance and support in determining needed biosafety and/or engineering controls.*

**Hazards associated with support materials** – Support materials in the 3D print matrix may contain harmful agents (e.g. phenyl phosphates associated with thermoplastic acrylics). These can be hazardous during use, and downstream waste handling.

**Powder resins and metals** – Reactive and highly combustible powder metals, as well as other resinous materials may be used in powder bed or direct energy deposition processes. These have applications in the construction of metal/alloy or other structural and functional tools and parts. Finely divided metal powders, such as titanium and aluminum, as well as other resin powders can be spontaneously combustible (pyrophoric) causing fires. The user must eliminate sources of potential ignition and not store the powder materials in a manner which may contribute to an explosion hazard. Class D metal fire extinguishers are required with use of metal powders. Users must follow specific manufacturer instructions and verify that electrical equipment and wiring are suited for the application. These applications use very high heat and may expose users to thermal injury, as well as potential inhalation of the powders or associated fumes.

Do to the hazardous nature of these materials and applications, *Standard Operating Procedures (SOPs)* are required. *Contact the Facility Coordinator/Safety Officer (FC/SO) or Campus Safety liaison to verify SOP’s are integrated into Unit Specific Plans for the research area, and as part of the Laboratory Research and Safety Plan for the department or work unit.*

Consult the 3D printer manufacturer website to locate **Safety Data Sheets (SDS’s)** (previous material safety data sheets) to understand and evaluate the specific health and safety hazards associated with the 3D print materials used.

**Equipment-Specific Hazards**

As previously noted, in addition to health hazards, examples of equipment-related hazards may include:

* Thermal/ Hot surfaces: Print head block and U/V lamp
* Electrical/ High voltage: Electrical components, connections including U/V lamp connector, circuits, conductors, etc. operating at 50 volts or higher must be guarded. Electric outlets must be safety-certified with grounding wire intact.
* Ultraviolet radiation/U/V lamp: Don’t look at the lamp; make sure U/V screen is intact.
* Guarding: Pulleys, chains, belts, rods, carriages, fan blades, rotating/moving parts (i.e. printing assembly), power transmission apparatus and any other type of pinch point must be guarded.

***NOTE: Shields/ guards/ covers installed by the manufacturer must not be removed/ remain in place and be utilized.***

***Consult Penn State EH&S for support in conducting hazard assessments, and for other controls support as early as possible during 3D printer planning, design, and installation.***

***What about 3D printer installations and maintenance?***

**Consumer-Grade 3D Printers** – Must be installed and maintained according to manufacturer’s instructions, and in well-ventilated areas.

**Industrial-Grade 3D Printing Systems** – Must be installed at the direction of the manufacturer, operated by manufacturer-trained users, and serviced by the manufacturer or personnel trained by the manufacturer.

***What about Operator/ User training?***

*Persons working with hazardous chemicals in 3D printing are minimally required to take an* [EH&S hazard communication class](https://apps.opp.psu.edu/ehs_training/course_list.cfm), *depending on their work environment:*

* Hazard Communication (Hazcom) (Non-Lab Setting), or
* Laboratory Safety & Laboratory Hazard Communication (Laboratory setting).

Industrial grade 3D printing applications shall additionally require orientation/training, as recommended by the manufacturer.

***Consult Penn State EH&S to make sure you receive the correct training(s) before operating a 3D printer.*** If biomaterials are used, Biological Safety training is required.

**General Safety Considerations**

1) Always follow manufacturer guidelines.

2) Consult EH&S for a hazard assessment when considering modifications/ novel uses.

3) Notify coworkers before beginning non-routine and hazardous work.

4) To prevent respiratory irritation, ventilate areas where model and support materials are used. *Consult FC/Safety Officer and EH&S for assistance and support with new installations and determining ventilation rates.*

5) Once a printing job is started, do not open cover, or defeat/override interlock switch.

6) If interlock safety switch fails, do not use the printer.

7) As determined necessary by hazard assessment, and in addition to all pertinent laboratory personal protective equipment (PPE), chemical protective gloves and suitable dust mask may be required when accessing the printer stage after printing.

8) Uncured material may be hazardous; wear suitable/ recommended glove protection.

9) If material can splash, wear safety goggles.

10) In the event of leak/ spill of printing material cartridges, use solvent-absorbent pads for model/ support material spills. Dispose clean-up materials as chemical waste. *Contact Penn State EH&S when responding to any major spills.*

11) Keep model and support materials away from areas where cosmetics are applied, or food and drink are stored, prepared or consumed.

**Specific Safety Considerations – Chemical-Based Support Material Removal**

**Support Material Removal by Hand**

* In addition to standard laboratory safety PPE, wear nitrile gloves and/or cut-resistant gloves and ANSI Z87.1-compliant safety glasses to protect the eyes from projectiles if removing the support materials by hand. Dispose of the used material as solid chemical waste.

**Removal of Support Material by Chemical Dissolution**

* Support material can be dissolved in an alkaline (base) bath containing a 2% solution of sodium hydroxide (caustic soda) at pH 13.
* Sodium hydroxide is corrosive and can cause chemical burns, scarring and blindness.
* Mixing sodium hydroxide with water generates significant heat that could ignite other materials.
* Sodium hydroxide should always be added to water and not vice versa.

**Personal Protective Equipment:**

To avoid chemical exposure while using the caustic and corrosive bath, create a barrier through personal protective equipment including:

* laboratory coator smock,
* chemical-protective gloves (suitable for use with applicable chemicals),

*Note: Users should refer to a suitable* [Chemical Compatibility Chart](http://www.showagroup.com/innovation/chemical-resistance) *for guidance.*

* splash-protective face shield or goggles,
* rubber apronshould be worn when pouring large amounts of corrosive or concentrated materials, i.e. more than 1 liter,
* face shieldoffers additional protection and prevents stray splatters from reaching the face,
* long pants and shoesthat cover and protect the feet - splashes often land below the waist.

**Safety Using the Corrosive Bath**

The caustic/corrosive bath shall be kept in a secondary container or tray to catch any spills or splashes. Spills shall be cleaned up promptly. Chemically-compatible and caustic/corrosion-resistant tongs can be used; however, be aware that splashes can occur if objects are not held tightly and are dropped.

pH paper should also be available and used where practicable. The sodium hydroxide solution (bath) may settle and liquid at the top of the bath may be neutral pH, while the lower layer may become very concentrated and alkaline.

Before adding more alkaline material to raise the pH, carefully mix the bath before measuring the pH to avoid making the bath more alkaline than intended.

**Alkaline Bath Emptying and Waste Disposal**

When the bath is emptied it cannot be diluted and poured down the drain because:

1. A pH>10 is caustic, corrosive, and harmful to the environment and plumbing, and
2. Some components of the dissolved support material are harmful to aquatic life. Therefore, the alkaline bath must be disposed of as hazardous waste. *Refer to* [*Penn State Policy SY20*](http://guru.psu.edu/policies/SY20.html) *for Hazardous Waste Disposal.*
3. Some manufacturers such as Stratasys collect the used bath materials for recovery of the thermoplastics and for proper disposal. Proper waste disposal of chemical waste must be arranged or coordinated by Penn State EH&S. Do not dilute waste and pour down the drain.

***Consult Penn State EH&S for additional assistance and support.***

**Material & Waste Container Labeling**

1) Containers shall be labeled in accordance with the [Penn State Chemical Container Labeling Guide](http://ehs.psu.edu/sites/ehs/files/chemical_container_labeling_labs_feb_15.doc), found at the EH&S website, Laboratory Safety Section, Resources page. *Label waste containers and properly store according to Penn State* [*Laboratory Research & Safety Plan (Policy SY43)*](http://guru.psu.edu/policies/SY43.html) *and* [*Penn State Policy SY20*](http://guru.psu.edu/policies/SY20.html) *for hazardous waste disposal requirements*.

***Contact EH&S for assistance or to schedule chemical waste pick-up.***

**Emergency Response & Spill Cleanup**

Caustic and corrosive materials quickly destroy skin or tissue if splashed on the body or in the eyes. To avoid destruction of skin or tissue upon exposure, corrosive materials need to be rinsed immediately if splashed on the body or in the eyes; therefore, a safety shower and eyewash is required in each area.

Use of the corrosive bath requires that a spill response kit be present and equipped with caustic neutralizer (such as [Amphomag® Universal Spill Neutralizer](https://www.amphomag.com/productOverview.aspx)) and caustic absorbent pads. This is important if there is a spill of alkaline bath material while adding or removing items, or while changing the contents.

Chemical spills that cannot be quickly and readily cleaned-up must be reported to EH&S according to [SY20](http://guru.psu.edu/policies/SY20.html) procedures. *Consult Penn State EH&S for information and support regarding spill planning and response.*

**Resource Links**

The subsequent resource links may be referenced supporting safe installation and operation of 3D printing processes:

**Environmental Health & Safety**

1. [*Ultrafine particles emitted by commercial desktop 3D printers*](http://ec.europa.eu/environment/integration/research/newsalert/pdf/commercial_desktop_3D_printers_emit_ultra_fine_particles_48si9_en.pdf). European Commission, [Science for Environment Policy](http://ec.europa.eu/environment/integration/research/newsalert/pdf/commercial_desktop_3D_printers_emit_ultra_fine_particles_48si9_en.pdf), Thematic Issue 48, February 2015.

<http://ec.europa.eu/environment/integration/research/newsalert/pdf/commercial_desktop_3D_printers_emit_ultra_fine_particles_48si9_en.pdf>

2. [*Ultrafine particle emissions from desktop 3D printers*. Stephens et. al., Atmospheric Environment, 79 (2013) 334-339](http://www.sciencedirect.com/science/article/pii/S1352231013005086).

3. [Carnegie-Mellon University 3D Printing Safety](http://www.cmu.edu/ehs/fact-sheets/3D-Printing-Safety.pdf)

4. [Emissions of Ultrafine Particles and Volatile Organic Compounds from Commercially Available Desktop Three-Dimensional Printers with Multiple Filaments, Azimi et. al., ES&T, 2016](http://pubs.acs.org/doi/pdf/10.1021/acs.est.5b04983)

5. [Acrylonitrile-Butadiene-Styrene Copolymers (ABS): Pyrolysis and Combustion Products and their Toxicity - A Review of the Literature, Rutkowski and Levin, Fire and Materials, 1986](http://fire.nist.gov/bfrlpubs/fire86/PDF/f86017.pdf)

6. [3D Printing Rules & Safety Do's and Dont's - MIT](http://makerworks.mit.edu/wp-content/uploads/2015/03/3DPrintingRulesSafety.pdf)

7. [Warning - How Safe is Your Desktop 3D Printer, King, 3D Print Headquarters, 2015](http://3dprinthq.com/desktop-3d-printer-safety/)

8. [OSHA Regional News Release, USDOL Region 1 - 3D Printing Firm Cited, May 20, 2014](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=26019)

9. [Health and Safety Considerations for 3-D Printers in the Era of Rapid Prototyping, Kalil, MIT Lincoln Lab](https://www.aiha.org/get-involved/LocalSections/NewEngland/Resources/Presentations/Heath%20and%20Safety%20Considerations%20for%203D%20Printers%20in%20the%20Era%20of%20Rapid%20Prototyping.pdf)

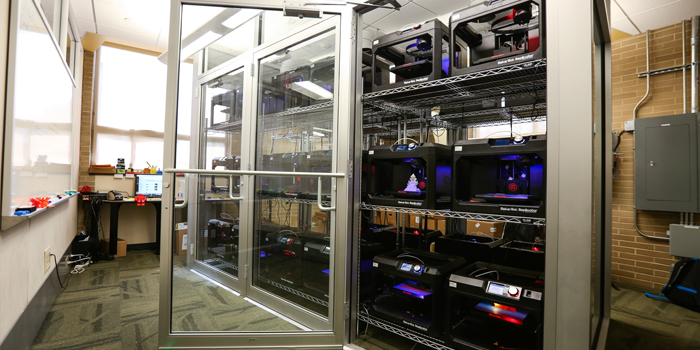
10.[NIOSH Control Measures Critical for 3D Printers](http://www.cdc.gov/niosh/research-rounds/resroundsv1n12.html)

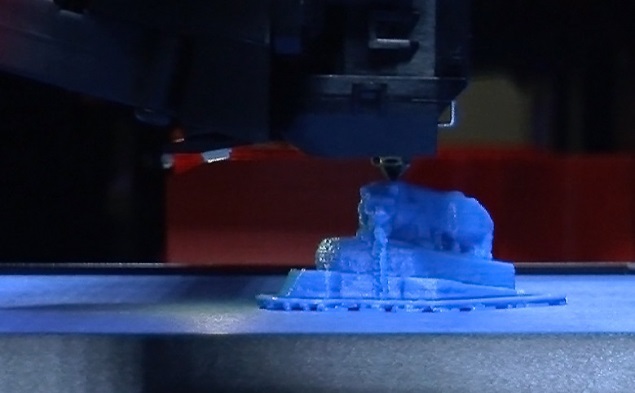
11.Carnegie-Mellon,Chemical Spill Response Kits –

<http://www.cmu.edu/ehs/fact-sheets/spillkitprepfactsheet.pdf>

**General Technology**

12. [3D Printing.com](http://3dprinting.com/what-is-3d-printing/)





Photos courtesy Penn State University Libraries, Pattee Library Knowledge Commons/ Maker Commons

1. *ASTM Committee F42 Additive Manufacturing Technologies (brochure).* ASTM International, 100 Barr Harbor Dr., P.O. Box C700, West Conshohocken, PA 19428-2959. September 2015. https://www.astm.org/COMMIT/F42Brochure\_Sept2015.pdf [↑](#footnote-ref-1)
2. *Approaches to Safe Nanotechnology-Managing the Health and Safety Concerns Associated with Engineered Nanomaterials.* Publication No. 2009-125. Dept. of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH). Cincinnati, OH. March 2009. [↑](#footnote-ref-2)
3. *Current Intelligence Bulletin 63- Occupational Exposure to Titanium Dioxide.* Publication 2011-160. Dept. of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH). Cincinnati, OH. April 2011. [↑](#footnote-ref-3)
4. *Current Intelligence Bulletin 65- Occupational Exposure to Carbon Nanotubes and Nanofibers.* Publ. No. 2013-145. Dept. of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH). Cincinnati, OH. April 2013. [↑](#footnote-ref-4)