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ASSESSING INHALATION HAZARDS IN 3D PRINTING

By David Ayers

The adoption of 3D-printing technologies has grown exponentially across industries, revolutionizing manufacturing, prototyping and customization. While it promises significant advantages, this technology introduces several potential hazards that necessitate rigorous hazard assessment and mitigation.

This article provides a hazard assessment that covers the multifaceted risks inherent to inhalation hazards found in 3D printing processes. This hazard assessment provides evidence-based insights into hazard identification and mitigation. The nature and severity of these hazards can fluctuate significantly depending on the specific 3D-printing technology employed (e.g., fused deposition modeling, stereolithography, selective laser sintering) and the materials used (e.g., plastics, metals, ceramics).

This hazard assessment explores inhalation hazards in 3D printing; however, it does not delve into the other prominent hazards frequently encountered in 3D-printing processes such as mechanical, electrical or thermal. Chemical emissions include volatile organic compounds (VOCs), ultrafine and nanoparticles, and potentially harmful gases from 3D-printing materials. These emissions pose potential health risks to operators and nearby personnel if not adequately managed and controlled.

Throughout this hazard assessment, specific research studies, governmental regulations and industry standards substantiate recommendations for mitigating the identified risks. By incorporating evidence-based practices, this assessment aims to empower individuals and organizations to harness the benefits of 3D printing while ensuring the highest levels of safety and responsibility in its application.

CONTROLLING INHALATION HAZARDS IN 3D PRINTING

- **Choose low-emission materials.** Opt for safer materials such as polylactic acid over high-emission filaments such as ABS to reduce VOC and nanoparticle emissions.
- **Implement engineering controls.** Use local exhaust ventilation, enclosed printer setups, and HEPA filters to capture airborne particles and gases at the source.
- **Ensure proper ventilation.** Maintain airflow and negative pressure environments to prevent the spread of harmful emissions into occupied spaces.
- **Use appropriate PPE.** Equip operators with gloves, safety glasses and respiratory protection, especially during printing and post-processing.
- **Conduct regular air quality monitoring.** Evaluate the effectiveness of controls and identify lingering exposure risks through sampling and analysis.
- **Train staff thoroughly.** Provide comprehensive training on safe material handling, emergency response and routine maintenance protocols.

Filaments & Resin

3D printer filaments and resins play a fundamental role in additive manufacturing, offering a wide array of materials for creating intricate and customized objects. However, these materials are not without their risks. Several types of 3D printer filaments are available, each with its own unique properties and characteristics. The choice of filament depends on the specific requirements of the 3D-printing project. Table 1 describes common types of filament.

Filaments and resins can emit VOCs, ultrafine and nanoparticles, and hazardous fumes during the printing process. These emissions can pose health risks to users. According to Zhang et al. (2022), "As 3D printers grow in application and use, health concerns over exposure to 3D printer emissions have been raised, especially when vulnerable populations are involved."

Ingestion or inhalation of filament or resin particles can lead to toxicity. Proper hygiene, storage and handling are essential to prevent exposure (MacCuspie et al., 2021; Stefaniak et al., 2017b). Extended contact with certain materials can lead to allergenic sensitization, causing allergic reactions upon subsequent exposure. According to Stefaniak et al. (2017b), "Carbonyl compounds such as aldehydes and ketones are associated with development of asthma." Ventilation, PPE usage and safe handling are critical (House et al., 2017; Würzner et al., 2022).

Health Hazards & Toxicology

While 3D printing offers many benefits, it also poses potential hazards, particularly related to toxicology that must be considered. Mitigating these risks requires a combination of proper ventilation, adequate PPE, safety training, maintenance protocols and adherence to regulatory standards. By proactively addressing these hazards, individuals and organizations can harness the benefits of 3D printing while safeguarding the well-being of workers and the environment. This article explores the toxicological and safety aspects of 3D-printing processes, focusing on the inhalation hazards.

Chemical Emissions

During 3D printing, filaments or resins can produce chemical emissions in the form of VOCs, ultrafine particles, and other potentially harmful chemicals. Some emissions may include styrene, formaldehyde and isocyanates (Stefaniak et al., 2017b). Additionally, post-processing techniques such as sanding, grinding or vapor smoothing can release particles and fumes. Inhaling these emissions can lead to respiratory irritation, allergic reactions and long-term health risks, especially in poorly ventilated spaces. Proper ventilation and air quality monitoring are essential (House et al., 2017).

Ultrafine & Nanoparticle Exposure

The 3D-printing process can generate ultrafine and nanoparticles, which pose inhalation risks due to their extremely small size (Taylor et al., 2021). For perspective, a human hair is about 80,000 to 100,000 nanometers in diameter. At this level, materials exhibit distinct properties due to their increased surface area, quantum effects, and altered mechanical and chemical behavior. Understanding and harnessing these properties has opened new frontiers in science and technology. Ultrafine and nanoparticles can penetrate deep into the respiratory system and potentially cause inflammation and adverse health effects. Minimizing exposure through appropriate ventilation, filtration and respiratory protection is vital.

3D Printer Exposure Assessments

Exposure assessments of 3D printer emissions have gained attention due to concerns about potential health risks associated with inhaling airborne particles and chemicals generated during the printing process. Some case studies have contributed to the understanding of exposure and post-processing exposure assessments.

NIOSH Case Study

NIOSH conducted a study (Stefaniak et al., 2017b) to assess emissions from desktop fused deposition modeling 3D printers using various filaments. The study found that certain filaments, particularly those containing acrylonitrile butadiene styrene (ABS), emitted high levels of ultrafine particles and VOCs. The emissions varied with filament type and temperature settings. This research emphasized the importance of adequate ventilation and proper filtration systems in 3D-printing environments, as well as the need for further investigation into the health effects of these emissions (Stefaniak et al., 2017b).

Lund University Case Study

Lund University in Sweden conducted research to investigate nanoparticle emissions from 3D printers (Azimi et al., 2016). The study revealed that 3D printing with polylactic acid filament generated significant concentrations of ultrafine particles, including nanoparticles. Exposure to these particles could pose health risks, particularly in enclosed spaces. This study highlighted the need for effective ventilation and particle filtration systems in 3D-printing environments, as well as ongoing research into the potential health effects of nanoparticle exposure (Azimi et al., 2016).

Study Takeaways

These case studies demonstrate that 3D printer emissions can contain potentially harmful substances, including VOCs and nanoparticles. The findings emphasize the importance of proper ventilation, air quality monitoring and the selection of materials to minimize inhalation exposure risks. Further research is ongoing to better understand the long-term health effects of exposure to these emissions and to develop effective safety guidelines for 3D-printing environments.

TABLE 1

COMMON TYPES OF 3D PRINTER FILAMENTS

Filaments or resin	Filament or resin characteristics
Polylactic acid (PLA)	PLA is one of the most popular 3D-printing materials. It is easy to print with, has low warping and does not emit strong odors during printing. PLA is biodegradable and made from renewable resources, such as cornstarch or sugarcane.
Acrylonitrile butadiene styrene (ABS)	ABS is known for its durability and impact resistance. It can withstand higher temperatures than PLA, making it suitable for functional parts. ABS can emit fumes during printing, so it should be used in a well-ventilated area.
Polyethylene terephthalate glycol-modified (PETG)	PETG is strong and durable and has good layer adhesion. This material is food-safe and commonly used for printing containers and functional parts.
Thermoplastic polyurethane (TPU)	TPU is a flexible filament known for its elasticity. It is often used for printing items such as phone cases, shoe soles and gaskets. TPU can be challenging to print due to its flexibility, so it may require special settings.
Nylon	Nylon is a strong, durable and lightweight material. It has good chemical resistance and is suitable for engineering applications. Nylon can absorb moisture from the air, so it should be stored in a dry environment.
Polyvinyl alcohol (PVA)	PVA is a support material often used with dual-extruder 3D printers. It dissolves in water, making it easy to remove support structures from complex prints. PVA is typically used in combination with other filaments such as PLA.
High-impact polystyrene (HIPS)	HIPS is another support material that can be dissolved in d-limonene, a common solvent. Its printing properties and strength are similar to those of ABS. HIPS is often used as a support material for ABS prints.
Metal and composite filaments	These filaments contain metal powders (e.g., copper, bronze, stainless steel) or other additives (e.g., carbon fiber). They can produce prints with a metallic or composite appearance and enhanced properties such as conductivity or strength.
Wood and stone filaments	These filaments contain wood or stone particles mixed with a polymer base. They can produce prints with wood- or stone-like texture and appearance.

Controls to Reduce, Eliminate 3D Printer Inhalation Hazards

The hierarchy of controls has five levels of actions to reduce or remove hazards. Using these controls can lower employee exposures and reduce the risk of illness or injury. The preferred order of action based on general effectiveness, starting with most preferable, is:

1) elimination
2) substitution
3) engineering controls
4) administrative controls
5) PPE

If possible, choose a low-emission or less-toxic filament or resin for 3D printing, such as polylactic acid instead of ABS, to reduce the overall emissions. After the filament or resin has been selected, to ensure that employees do not come into contact with inhalation hazards, look at engineering controls, such as:

- **Local exhaust ventilation systems.** These systems capture and remove emissions directly at the source. They consist of hoods, ducts, and filters that capture and filter airborne particles and chemicals (NIOSH, 2023).
- **Enclosures and controlled environments.** Sealing 3D printers within enclosures or controlled environments can limit the dispersion of emissions. These enclosures can have built-in ventilation and filtration systems (Stefaniak et al., 2017b).
- **High-efficiency particulate air (HEPA) filters.** HEPA filters are effective at capturing fine particles and can be incorporated into ventilation systems

to remove ultrafine particles generated during 3D printing (Azimi et al., 2016).

•**Negative pressure systems.** Negative pressure systems maintain lower air pressure inside the 3D printing area compared to surrounding spaces, ensuring that emissions are drawn away from the operator and confined within the printer enclosure.

•**Improved filtration media.** Upgrading filtration media with activated carbon or other advanced materials can aid in removing VOCs and odors from emissions.

•**Airflow management.** Optimizing airflow within the 3D-printing environment can ensure that emissions are effectively captured and directed toward filtration systems.

Once engineering controls are in place and confirmed to be operating effectively, then PPE and training can be implemented. To confirm engineering controls are effective, sample the air and determine whether all chemical and nanoparticle emissions are being captured. Employees should wear appropriate PPE as needed, including gloves, safety glasses and respiratory protection, when working with filaments and resins (Davis et al., 2019; NIOSH, 2023; Stefaniak et al., 2017a). For employees, provide comprehensive training on safe handling and storage of filaments and resins, such as hazard recognition and emergency response procedures that cover post-processing chemical handling. Establish procedures for handling solvents, filament and resin spills, leaks or incidents, and ensure that appropriate cleanup materials are available and accessible.

These controls can significantly reduce the emissions generated by 3D printers and improve the overall safety of the workplace. Employing a combination of these controls tailored to the specific 3D printing setup and materials used is often the most effective approach to mitigate emissions and protect the health of 3D printer operators.

Conclusion

There are several considerations to ensure the safety and well-being of employees working with or near 3D printers, such as associated inhalation hazards, toxicology and health risks, case studies of exposure assessments, and engineering controls for emissions reduction. The selection of filaments and resins used in 3D printing is important since these materials can emit VOCs and fine particles, posing health risks to operators and those in proximity. For this reason, the choice of materials and their potential toxicity must be carefully considered.

The toxicological aspects of 3D printing are multifaceted, encompassing chemical emissions, nanoparticle exposure and material toxicity. Health risks include respiratory irritation, sensitization and potential long-term effects due to exposure to hazardous materials. Findings from research and case studies emphasize the significance of proper ventilation, filtration and material selection for reducing exposure risks. Implementing engineering controls is crucial for mitigating 3D printer emissions. Measures such as local exhaust ventilation systems, enclosures, HEPA filters, negative pressure systems and improved filtration media can effectively minimize inhalation hazards.

By addressing these hazards through a combination of material selection, proper ventilation, suitable PPE and adherence to safety guidelines, individuals and organizations can harness the benefits of 3D printing while safeguarding worker health and promoting safety for their employees. Continued research, adherence to regulations and the development of best practices are essential in this rapidly evolving field to ensure a safe and sustainable future for 3D-printing technologies. **PSJ**

References

Azimi, P.Z., Zhao, D., Pouzet, C., Crain, N.E. & Stephens, B. (2016). Emissions of ultrafine particles and volatile organic compounds from commercially available desktop three-dimensional printers with multiple filaments. *Environmental Science and Technology 50*(3), 1260-1268. https://doi.org/10.1021/acs.est.5b04983

CDC. (2024). About hierarchy of controls. www.cdc.gov/niosh/topics/hierarchy/default.html

Davis, A.Y., Zhang, Q., Wong, J.P.S., Weber, R.J. & Black, M.S. (2019). Characterization of volatile organic compound emissions from consumer level material extrusion 3D printers. *Building and Environment, 160*, 1-20. https://doi.org/10.1016/j.buildenv.2019.106209

House, R., Rajaram, N. & Tarlo, S.M. (2017). Case report of asthma associated with 3D printing. *Occupational Medicine, 67*(8), 652-654. https://doi.org/10.1093/occmed/kqx129

MacCuspie, R.I., Hill, W.C., Hall, D.R., Korchevskiy, A., Strode, C.D., Kennedy, A.J., Ballentine, M.L., Rycroft, T. & Hull, M.S. (2021). Prevention through design: Insights from computational fluid dynamics modeling to predict exposure to ultrafine particles from 3D printing. *Journal of Toxicology and Environmental Health, Part A, 84*(11), 458-474. https://doi.org/10.1080/15287394.2021.1886210.

NIOSH. (2023). Approaches to safe 3D printing: A guide for makerspace users, schools, libraries and small businesses [DHHS (NIOSH) Publication 2024-103]. www.cdc.gov/niosh/docs/2024-103/default.html

Stefaniak, A.B., Hammond, D.R., Johnson, A.R., Knepp, A.K. & LeBouf, R.F. (2017a). Health hazard evaluation report: Evaluation of 3-D printer emissions and personal exposures at a manufacturing workplace (NIOSH HHE Report 2017-0059-3291). www.cdc.gov/niosh/hhe/reports/pdfs/2017-0059-3291.pdf

Stefaniak, A.B., LeBouf, R.F., Yi, J., Ham, J., Nurkewicz, T., Schwegler-Berry, D.E., Chen, B.T., Wells, J.R., Duling, M.G., Lawrence, R.B., Martin, S.B., Jr., Johnson, A.R. & Virji, M.A. (2017b). Characterization of chemical contaminants generated by a desktop fused deposition modeling 3-dimensional Printer. *Journal of Occupational and Environmental Hygiene, 14*(7), 540-550. https://doi.org/10.1080/15459624.2017.1302589

Taylor, A.A., Freeman, E.L. & Van der Ploeg, M.J.C. (2021). Regulatory developments and their impacts to the nano-industry: A case study for nano-additives in 3D printing. *Ecotoxicology and Environmental Safety, 207*(1), 111458. https://doi.org/10.1016/j.ecoenv.2020.111458

Würzner, P., Jörres, R. A., Karrasch, S., Quartucci, C., Böse-O'Reilly, S., Nowak, D. & Rakete, S. (2022). Effect of experimental exposures to 3-D printer emissions on nasal allergen responses and lung diffusing capacity for inhaled carbon monoxide/nitric oxide in subjects with seasonal allergic rhinitis. *Indoor Air, 32*(11), e13174. https://doi.org/10.1111/ina.13174

Zhang, Q., Davis, A.Y. & Black, M.S. (2022). Emissions and chemical exposure potentials from stereolithography vat polymerization 3D printing and post-processing units. *ACS Chemical Health and Safety, 29*(2), 184-191. https://doi.org/10.1021/acs.chas.2c00002

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