3D Printing In Schools and Colleges: Managing the Risks

The Health and Safety Executive (HSE) was involved with CLEAPSS in producing this guidance. HSE endorses the guidance, as it follows a sensible and proportionate approach to managing health and safety.

Introduction: Over recent years there has been an increase in the use of 3D printing in schools and colleges. Whilst this is an exciting and innovative new technology, there is now evidence that there are health and safety risks associated with the process of heating and extruding plastic filament to form 3D objects.

There are various 3D printing technologies. This document is concerned with Fused Filament Fabrication (FFF) which is the most commonly used technology in schools and colleges. FFF printing is a process of laying down melted plastic filament in a series of layers. The adjacent layers cool and bond together before the next layer is deposited (Figure 1 over page).

This document has been developed in collaboration with the HSE and provides information to users of this technology on how to work safely and mitigate potential associated risks. These mitigating actions are referred to as control measures.

This document is aimed at those who are responsible for purchasing and looking after 3D printing equipment in schools and colleges to ensure that employees and pupils are safe. This advice may also interest a wider audience, including home users of desktop 3D printers.

Why you should take notice of this advice? The use of this technology is relatively new and published studies have suggested that filament combustion products may present a risk to health when inhaled. Individuals most at risk include those with pre-existing asthma and breathing difficulties and those predisposed to developing asthma.

This document identifies areas that should be considered before purchasing and when using 3D printers, and recommends measures that should be put in place to reduce these risks. The term 'recommendation' is used to highlight the need for action(s) to be taken considering the most relevant regulations [2,3,4].

What does the Law require? If your business uses or creates substances, or carries out processes which might cause harm to health, the law requires you to control the risks. The term control can apply to actions taken, to processes, or to safety equipment, used to minimise employee's exposure to hazardous substances. Employers have legal duties under the Health and Safety at Work Act to ensure, so far as is reasonably practicable, the health, safety, and welfare at work of all their employees. This responsibility extends to other persons, such as pupils, students and visitors who may be affected by activities undertaken in the workplace. The Control of Substances Hazardous to Health Regulations (COSHH 2002)[1] requires employers to ensure that exposure is prevented or, where this is not reasonably practicable, adequately controlled. This can be achieved by applying the principles of good practice for the control of exposure to substances hazardous to health, as set out in COSHH.

COSHH risk assessment: An assessment of the risk of the potential hazardous substances and processes will be required, and a written assessment may be needed, informing how

work can be undertaken safely. Guidance for preparing a risk assessment can be found on the HSE website [3]. When thinking about your risk assessment, remember: a **hazard** is anything that may cause harm, such as chemicals, the **risk** is the chance, that somebody could be harmed, together with an indication of how serious the harm could be.

What do you need to consider when buying a 3D printer and filaments? Prior to purchasing a 3D printer and associated materials, there are a number of things to consider. It is recommended that only 3D printer equipment which carries a CE mark is purchased for use in schools and colleges. Where 3D printers can be purchased in kit form, it is recommended that the purchaser ensures that the supplier is able to provide evidence that the kit meets the quality and safety standards implied by CE marking.

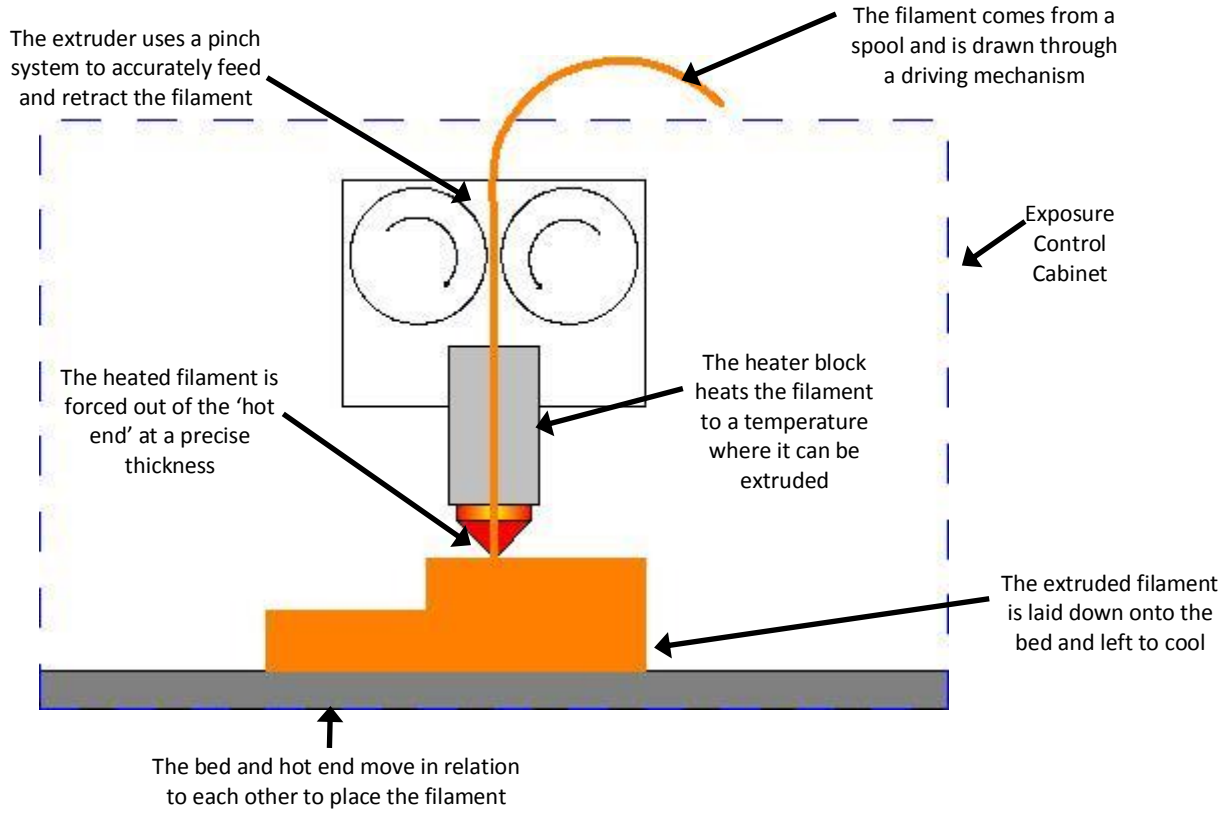


Figure 1 Diagram of a Fused Filament 3D printer inside an exposure control cabinet

Where should 3D printers be located? You will need to consider how much use you will make of the printer and how many printers you will put in one location. It is recommended that the room you use is well ventilated, with space for working around the equipment, and with an adequate power supply. It is also recommended that local exhaust ventilation (LEV) be used such as an 'exposure control cabinet' (Figure 1). This should be fitted with an adequate fan and filters to enable the removal of small particles and organic emissions from the melting of the filaments. It is important for the safety of pupils that access to this space is controlled by responsible individuals.

As a 3D printer is not an easily portable item of equipment it is recommend that the device is fixed in place. A number of additional safety considerations also apply:

- Some print runs can take many hours, so the ability to pause the print or to split the print job into smaller components may be necessary.
- In a school workshop, the power supplies to equipment should be controlled via a key-controlled electrical shut off. This switch should be lockable, accessible and checked regularly to establish that it is working at all times. This is an essential requirement for workshops, and other rooms, where machines are used; such as graphics rooms; rooms used for systems and control work and preparation rooms where machines are located.
- A 3D printer and any associated LEV may need to be on the same circuit as PCs and other equipment that does not get switched off if the emergency stop button is activated.
- The electrical supply to the machine will need to be fed via a conduit from a fused, labelled switch, which allows the machine to be isolated from the supply when maintenance or servicing is to be carried out. This should not be a standard stand-alone 13A plug which could be accidentally plugged in restoring power to the machine during maintenance.
- Additional stop switches which provide 'no voltage release' capacity may need to be provided.
- Third limb switches, such as foot stops, may need to be added.
- Appropriate and effective guards should be provided, which could be interlocked to the machine start system.
- Access to moving parts such as gearbox or belt covers should be secured, so that a specialist tool must be used to open the cover(s).
- Subject to a local risk assessment, the machine may require LEV to be installed e.g. an exposure control cabinet.

What Features of a 3D Printer Do You Need to Consider? There are many different types of 3D printers in use but typically the affordable 3D desktop printer market is dominated by FFF printers. When making your purchasing decisions you need to consider:

- Do you expect to print with different materials or colours at the same time? Single filament printers are common and more affordable, but some printers can use two or more filaments. These may be of the same material and different colours, or could be of different materials.
- What type of printing applications are you considering? Will the 3D printer be used for construction projects, for design and art work, or for electronics projects? This can influence the type of filament material you purchase.
- What is the best temperature range for the print head? The temperature range will influence the types of filament materials you can use because different materials melt at different temperatures. Some 3D printers also have the facility to heat the bed of the machine and this helps the first few layers of the print to adhere.
- What is the best print bed size? The print area constrains the maximum size of the print. The larger the print, the longer the print time.
- What size (diameter) filament do you require? This can affect the amount of material that is laid down in each layer and the speed of completing the build. Most desktop

machines use 1.75mm filament, which is extruded at 0.2mm. Some printers use 3mm filament, which also extrudes at 0.2mm. There are no significant differences in using the different sizes, but machines can usually only use one size.

- Should the desktop printer be enclosed? It is recommended that desktop 3D printers are purchased with an exposure control cabinet already fitted to reduce emissions, prevent injuries from moving and hot parts, and to add security. Exposure control cabinets can also help to maintain the temperature environment of the printing space and improve the quality and success of printing. Desktop printers can be purchased as complete machines or constructed from kits which include air extraction and filtration units. You should always check carefully that this is the case as some printers have openings at the top which will allow particles and gases to escape. Some desktop 3D printers are of an open frame design. It is recommended that if other LEV systems are not available, exposure control cabinets are placed over open frame printers.
- What do you need to do to maintain this equipment safely? 3D printers should be maintained by competent individuals. Some printers have no user serviceable parts.
- What software do you require to run the machine and to design the objects you want to build? All 3D printers need to be linked to computer aided design (CAD) software and some additional software applications may also be required to set up and run the printer. Prior to purchasing a 3D printer it is prudent to check what sort of software is most appropriate for the printer, taking into consideration the platform you use and operating system. Setting secure passwords to prevent misuse of the CAD software is something that you may need to consider.

Choosing Suitable Consumables: There are many different types of filament material and you may be tempted to save costs by purchasing these more cheaply over the internet. However, it is important to know what the filament is made from, and that the company supplying it has provided you with good information and technical support. A good sign is that the supplier of filaments can provide you with a Safety Data Sheet (SDS) that provides clear and specific information about the constituents of the filaments and the products produced when the filament is used in the printer.

What Types Of Filament Are Suitable In An Educational Setting? It is recommended that wherever possible you use PLA to reduce the risk from fumes and particulate emissions. Filaments can be affected by the temperature, humidity (some absorb moisture) and light (some are light sensitive), so should be stored in sealed, dry and dark containers. Most filament waste can be placed into your recycling system but non-recyclable materials should be disposed of in small amounts via your normal waste carrier. Any hazardous waste produced through the printing process will need to be removed by a licenced carrier

What do you need to consider when preparing your risk assessment?

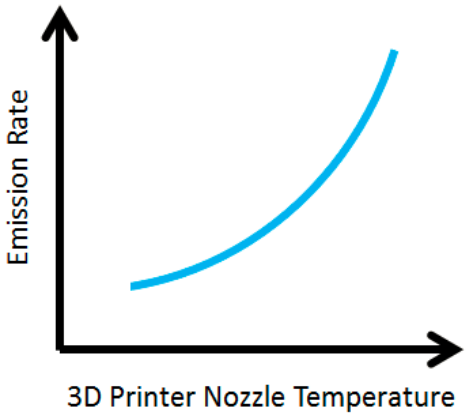
Hazards: The following are possible hazards a school/college should consider when carrying out a risk assessment:

- Moving components
- Heated components

- Ultrafine particle emissions
- Chemical emissions
- Electricity
- Heavy equipment
- Hazardous waste
- Cleaning chemicals

Relevant risks:

Inhaling emissions from the 3D printer: Standing close to the printer and spending long periods near the printer during its operation will increase the risk of inhalation of particulate and chemical emissions. More emissions are produced by higher printer nozzle temperatures (Figure 2). For some individuals, brief exposure to these emissions may trigger symptoms but there may also be longer-term health risks for individuals who spend long periods using 3D printers.



Contact with moving and heated parts of the printer: Body parts, hair and clothing could become trapped in the moving printer parts and skin could become pinched between belts and drive wheels. The nozzle of the 3D printer can reach high temperatures of between 200 - 300^{o}C. Some 3D printers have a heated print bed reaching to between 50 - 100^{o}C. The skin could be severely burnt if it comes in to contact with these heated parts. Printed components, immediately after the printing finishes, may also be hot enough to burn.

Electrical burns and shocks: Any equipment connected to the mains supply can possibly give an electric shock to the user, causing fatalities or injuries and burns. Poor installation and maintenance can also lead to damage of the equipment.

Musculoskeletal injuries caused by lifting and moving 3D printers: Some printers are heavy. Poorly conducted manual handlings tasks increase the risk for musculoskeletal injuries.

Control Measures:

Minimising exposure to hazardous substances: To minimise exposure to hazardous substances, COSHH sets out important principles that need to be addressed in the risk assessment. In summary when applying these principles the following is recommended.

i) Minimise the use of hazardous processes and materials:

- If you are unsure about which types of printers are safer by design, and which types of filament materials are least hazardous, seek advice from CLEAPSS[7] or from suppliers that conform to EU and GB Health and Safety and Equipment Safety Legislation.
- Choose PLA as your main type of filament material and avoid using more hazardous filaments such as ABS.
- Reduce the printer nozzle temperature to the lower melt range specified by the filament supplier. This information should be in the product information sheet but if in doubt contact your supplier.

- Consider how many printers you are running in a room and whether the room has adequate ventilation. If possible do not place many printers in one room particularly if the room is small and/or poorly ventilated.

ii) Containment for 3D Printers:

- The best solution is to purchase a 3D printer that is fully enclosed including filters to remove particulate and chemical emissions. Alternatively use a bespoke exposure control cabinet to cover each printer.
- A well-designed exposure control cabinet should include a fan to draw the air through a suitable filter for ultrafine particulates e.g. HEPA filter, and a carbon filter for capturing volatile organic chemicals (termed VOC).
- All types of enclosed printers, or exposure control cabinets, will take time to clear emissions once the printing has finished, so allow an appropriate clearance time before opening the enclosure after printing. Follow the enclosure manufacturer's guidance.
- An exposure control cabinet will prevent access to the working area, and therefore prevent contact with hot and moving components.
- Properly installed and maintained equipment will prevent access to electrical components and therefore reduce the risk of electric shock injuries or burns.
- An exposure control cabinet fixed securely in place will prevent movement and unauthorised removal of the equipment.
- To minimise the risk of musculoskeletal injury caused by lifting and moving printers, suitable lifting equipment and trolleys should be used.

Cleaning and Maintenance: Injuries from the equipment and exposure to contaminants on the printer surfaces can occur, as well as from chemical products used to clean printers. Chemicals or materials used for cleaning may interact with other materials increasing the risk of chemical emissions.

- Prior to use, the operator should carry out a visual check of all electrical connections
- The machine must be switched off and isolated from the mains before cleaning or carrying out maintenance.
- The person cleaning or maintaining the machine should be competent. When accessing the interior build space of the machine ensure that all components have had time to cool.
- Take care to ensure that belts, pulleys, bearings and other mechanical components are identified and the operator avoids touching them, unless carrying out maintenance on those parts.
- Follow the manufacturer's instructions for suitable cleaning processes and chemicals, and with regard to user serviceable components. Avoid using harsh or hazardous chemicals and strong organic solvents for cleaning work. Alcohol based wet wipes containing suitable detergent and disinfectants are suitable for this purpose but avoid cloths soaked in water in order to protect the electronics.

- Use disposable paper towel to dry and clean the equipment, not rags.
- Filaments should be replaced by a competent individual ensuring care with respect to moving and heated parts.
- Guards and enclosures must be replaced when cleaning and maintenance work is completed.
- Where an exposure control cabinet is used, the filters should be checked and changed regularly as this qualifies as an LEV system. A "*Thorough Examination and Test' (TExT) is required and must be carried out by a competent person*". Further advice can be found G225 – Local Exhaust Ventilation in D&T available on the CLEAPSS website [7].

Manual handling: Use a dedicated location for the printers and fix them in place. If the 3D printer needs to be moved, use best practice for manual handling as described on the HSE website[5].

Electrical safety: Before switching on the 3D printer, visually check that all electrical connections are in a good condition. Ensure that the machine is correctly installed, and run the power cable via a conduit from a fused, labelled isolating switch. Advice on safe working with electrical equipment can be found on the HSE website[6].

Further Information

HSE Guidance

1) Control of Substances Hazardous to Health (COSHH): http://www.hse.gov.uk/coshh/

2) Provision and Use of Work Equipment (PUWER): http://www.hse.gov.uk/work-equipment-machinery/puwer.htm

3) How to carry out a COSHH risk assessment?: http://www.hse.gov.uk/toolbox/harmful/coshh.htm

4) Management of Health and Safety at Work Approved Code of Practice: http://www.hse.gov.uk/pubns/books/l21.htm

5) Manual Handling and Musculoskeletal Disorders: http://www.hse.gov.uk/msd/manualhandling.htm

6) Electrical safety at work: http://www.hse.gov.uk/electricity/index.ht

Other Sources of Guidance

7) Consortium of Local Education Authorities for the Provision of Science Equipment (CLEAPSS): http://www.cleapss.org.uk/

8) Building Bulletin 101 (GOV.UK): https://www.gov.uk/government/publications/building-bulletin-101-ventilation-for-school-buildings

9) Scottish Schools Education Research Centre: https://www.sserc.org.uk/