

SAFETY IN MAM

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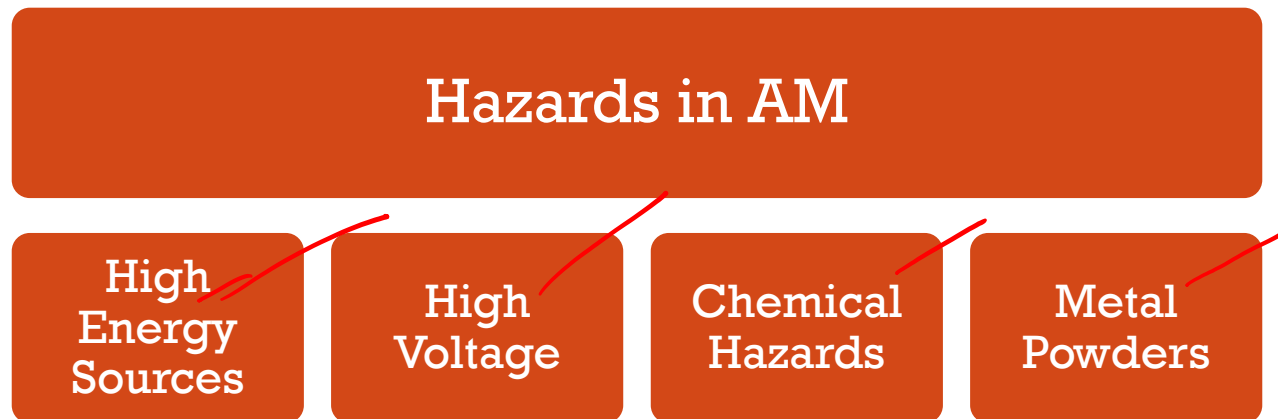


INTRODUCTION

- The safety aspects in additive manufacturing are among the most crucial elements that need to be carefully considered. To create a space that is productive for everyone, a safe outlook is crucial.
- Therefore, it is essential to be aware of the dangers to health and safety prior to an accident and to take action to reduce or eliminate those risks.



POTENTIAL HAZARDS OF ADDITIVE MANUFACTURING



HIGH ENERGY DENSITY SOURCES

Laser and electron beams are the two high energy density sources most frequently used in additive manufacturing.

A) Laser:

- a) The American National Standards Institute (ANSI) created a series of standards called ANSI 2136.
- b) The Maximum Permissible Exposure (MPE) is the maximum amount of laser radiation to which a person may be exposed.



HIGH ENERGY DENSITY SOURCES

c) The specifics of different standards are displayed without risk or negative biological effects on the skin or eyes.

d) The list of MPE values for the eye and skin with regard to laser wavelength and likely laser exposure period is provided in ANSI Z136.



HIGH ENERGY DENSITY SOURCES

Standard	General description
ANSI Z136.1 Safe <u>use of lasers</u>	Provides direction to industry, military, research and development (labs), and higher education (universities).
ANSI Z136.4 Recommended laser safety <u>evaluations</u>	Provides regulation for measurement techniques required for the classification and assessment of <u>optical radiation risks. settings.</u>
ANSI Z136.5 Safe <u>use of lasers</u> in <u>educational institutions</u>	Addresses laser safety concerns in educational institutions
ANSI Z136.9 Safe <u>use of lasers</u> in <u>manufacturing environment</u>	Intended to protect individuals with laser exposure <u>manufacturing environments.</u> The standard contains <u>industries. rules and actions</u> to ensure laser safety in public and private



HIGH ENERGY DENSITY SOURCES

Nd:YAG

200mW/cm²

- An expert does the NHZ calculation, typically a Laser Safety Officer (LSO).
- The following relationships are indicative of a dangerous laser:

a) For continuous wave laser :

$$\frac{\text{Laser Output (W)}}{\text{Limiting Aperture (cm}^2\text{)}} > MPE$$

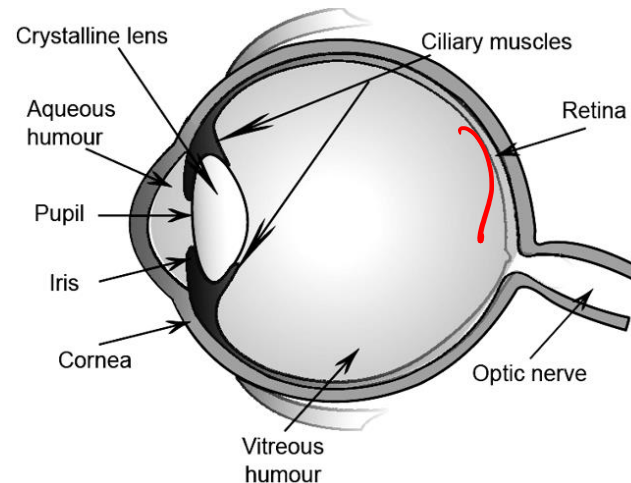
b) For single pulse lasers:

$$\frac{\text{Laser Energy Output (J)}}{\text{Limiting Aperture (cm}^2\text{)}} > MPE$$



HIGH ENERGY DENSITY SOURCES

A) Ocular effect: Since the capacity of light to enter through ocular components in the eye varies with the light's wavelength, the ocular effect of laser exposure is explained with reference to the wavelength of the laser beam. The numerous eye parts are shown in figure.



HIGH ENERGY DENSITY SOURCES

Optical Band light	Wavelength (100-400 nm)	Effect	Hazard
<i>Ultraviolet Light (100-400 nm)</i>			
Ultraviolet A	315-400 nm	Can penetrate the aqueous humour and absorb on the <u>eye lens</u>	<u>Cataract</u>
Ultraviolet B	280-315 nm	Can get absorbed on the <u>cornea</u> and aqueous humour. Cannot penetrate to the <u>iris</u> or eye lens	Photokeratitis (welder's flash) and erythema (reddening)
Ultraviolet C	100-280 nm	Can get absorbed on the <u>cornea</u> and <u>aqueous humour</u> Cannot penetrate to the <u>iris</u> or eye lens	-

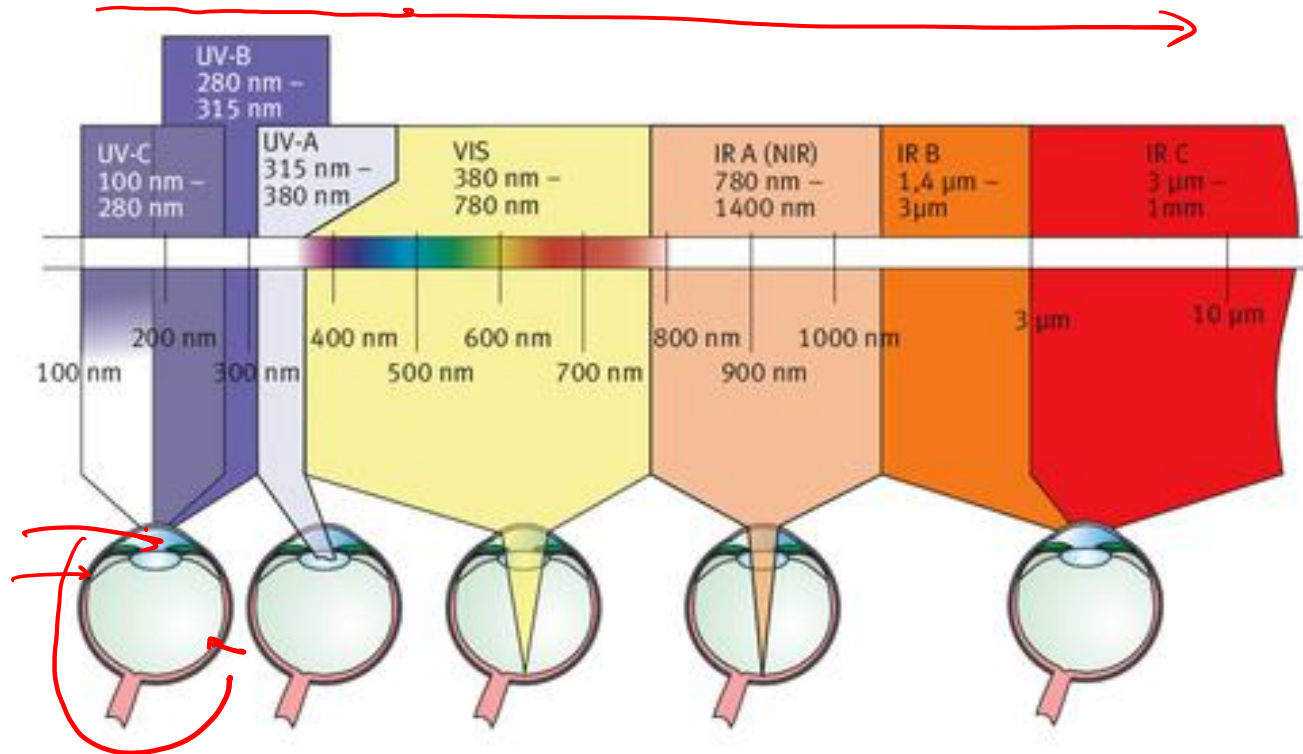


HIGH ENERGY DENSITY SOURCES

Optical Band light	Wavelength (100-400 nm)	Effect	Hazard
<i>Visible light (400-780 nm)</i>			
Visible light	400-780 nm	Highly penetrating and absorbs primarily on the <u>eye retina</u>	Irradiance above <u>10 W cm⁻²</u> can result in <u>tissue damage</u>
<i>Infrared light (780 nm-1 mm)</i>			
Infrared A	780 nm-1400 nm	Similar to <u>visible</u> light	Affects the <u>retina</u>
Infrared B	1400 nm-3000 nm	Will not enter <u>past the lens</u>	Causes <u>cataract</u>
Infrared C	3000 nm-1 mm	Absorbs <u>mainly on the cornea</u>	Can <u>result in burning</u> , if <u>irradiance</u> is high

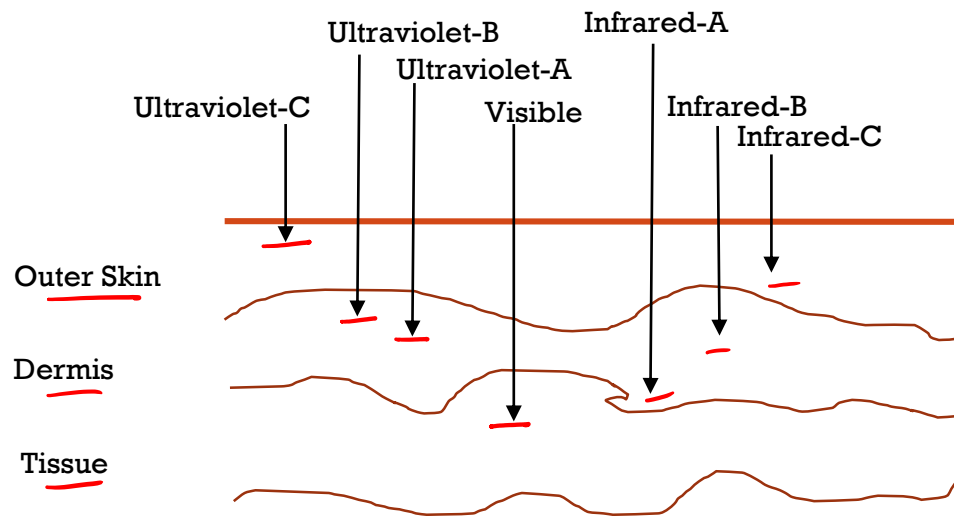


HIGH ENERGY DENSITY SOURCES



HIGH ENERGY DENSITY SOURCES

B) Skin effects: The laser with different wavelength has a different depth of penetration. The depth of penetration of radiation in human skin varies with wavelength:



HIGH ENERGY DENSITY SOURCES

- **Ultraviolet C and Infrared C** – Absorbed by the outer and dead skin layers, which can result in burning
- **Ultraviolet B and Infrared B** – Penetrate fairly deeper into the living skin tissue
- **Ultraviolet A and Infrared A** – Penetrate even deeper into the skin
- **Visible light** – Penetrates to the deepest skin layer



HIGH ENERGY DENSITY SOURCES

Classification of lasers

Class	Type and General Description of laser in the class
Class 1 ✓	A laser <u>not capable to produce radiation levels</u> which can cause damage.
Class 2 ✓	A visible laser (<u>wavelength: 400-700 nm</u>) which cannot surpass the maximum ^(MPE) permissible exposure for ocular exposure time less than <u>0.25 s</u> .
Class 3a ✓	A laser whose output is less than <u>5 times the ocular maximum permissible exposure</u> .
Class 3b	<p>A laser whose output is more than <u>5 times the ocular maximum permissible exposure</u> but which:</p> <p>a) cannot exceed an average <u>radiant power greater than 0.5 W</u> for <u>0.25 s or longer</u> ^{continuous}</p> <p>b) cannot produce <u>radiant energy greater than 0.125 J</u> for exposure times less than <u>0.25 s</u> ^{single pulse}</p>
Class 4 ✓	A laser with output more than the <u>limits for Class 3b lasers</u>



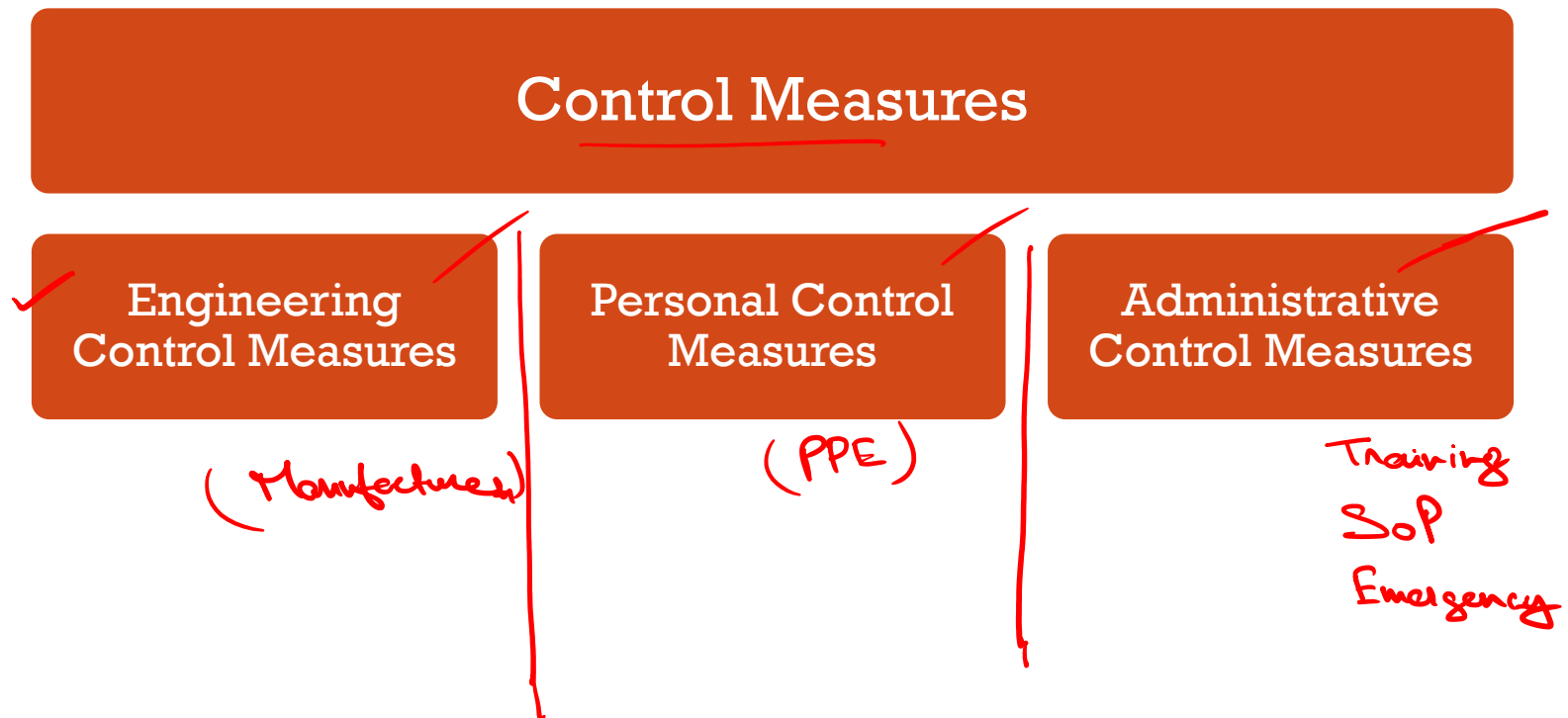
HIGH ENERGY DENSITY SOURCES

- The penetration results in a different effect on skin, based on the laser intensity. The effect of laser light is presented below:

Effect	Reason	Damage	Depends on
Thermal effects	Rate of energy absorption exceeds the heat <u>transfer</u> rate that the <u>tissue</u> can handle in the <u>exposed</u> <u>volume</u>	<u>Burning</u>	First degree of burn, if irradiance $> 12 \text{ W cm}^{-2}$ Second degree of burn, if irradiance $> 24 \text{ W cm}^{-2}$ Third degree of burn, if irradiance $> 34 \text{ W cm}^{-2}$
Photochemical effects	Induced <u>chemical reactions</u> in tissue from the absorption of ultraviolet radiation	<u>Burning</u>	Amount of energy absorbed in a given volume of tissue
Delayed effects	Due to the absorption of <u>ultraviolet radiation</u> which can cause <u>mutation</u> in the <u>DNA</u> of <u>living</u> <u>cells</u>	<u>Skin Cancer</u>	Net dose of radiation received and whether the exposure is acute (short period) or chronic (long period)



HIGH ENERGY DENSITY SOURCES



LASER HAZARDS CONTROL MEASURES

Control measure	What is it?	Purpose
Remote interlock connector	The electrical connection between the power supply and an exterior device (pressure switch, light or audible alarm)	Automatically triggers a warning light or audible signal every time the laser is energized, or automatically turns off the laser, if the sensor at the entryway is triggered
Beam stop or attenuator	To stop or weaken the laser beam at the exit port or somewhere along the beam path using a mechanical shutter or other devices	To instantly stop laser or when a lower beam irradiance or radiant exposure is desired To stop the beam after its useful path
Activation warning system	A light, a loud alarm, a distinctive sound from laser auxiliary equipment or an oral countdown	To make people aware before startup of the laser To remind people to stand away from the direct laser beam and wear safety goggles



LASER HAZARDS CONTROL MEASURES

Control measure	What is it?	Purpose
Remote firing and monitoring	Use of a booth or barrier that interrupts between the laser control panel and all probable laser beam pathways	Permits firing and observing the laser from a location without exposure to direct, reflected or scattered radiation above the maximum permissible exposure limit for the eyes and skin
Warning signs/labels	Cautioning symbols and tags for lasers and laser systems	<ul style="list-style-type: none">• Notify laser hazard in the area• Specify the particular rule in effect relative to laser controls• Display the seriousness of hazard present (e.g. class of laser, nominal hazard zone identification)• Offer directions for the usage of laser goggles and risk prevention



LASER HAZARDS CONTROL MEASURES

Control measure	What is it?	Purpose
Diffuse reflective material	Equipment and components that produce only diffuse reflections	Reduces the hazard to personnel
Panic button	Large red mushroom-shaped knob connected to the laser power supply	Enables the instant shutdown of a laser in case of an emergency
Entryway controls	Doors and barriers that are interlocked and not interlocked to the laser power supply	Stop people from exposure to unsafe levels of the laser zone
Beam path control	Use of a mechanically stable, optical table Careful placement of optical components to confirm that the beam path is clear. Keeping the beam path above or below eye level covers, etc.	Decrease the nominal hazard around the laser



LASER HAZARDS CONTROL MEASURES

Control measure	What is it?	Purpose
Exhaust ventilation	Usage of screens, curtains, window Canopy hoods and enclosing hood	Eradicates air contaminates created by the laser interaction with the target material
<u>Personal Control Measures</u>		
Protective eyewear	Goggles, face shields, spectacles and prescription filters or reflective coating	Weakens the laser radiation below the level ocular maximum permissible exposure (Continued)



LASER HAZARDS CONTROL MEASURES

Control measure	What is it?	Purpose
Skin protection	Fresh shields, laboratory coats and cotton gloves	Safeguards the skin from ultraviolet radiation to prevent skin cancer
<u>Administrative control Measures</u>		
Security and access	Control over keys to entryway doors Control over keys and passwords for energizing the laser Area monitoring by security personal, cameras, etc.	Avoid the risk of exposure to laser radiation and authorized entry
Training	Training may include the following topics: Basics of laser and laser operation Biological effects of laser radiation Varieties of threats and control methods Location-specific actions Duties and responsibilities of personnel	To ensure that persons are aware of the hazards associated with the use of the laser or the hazards involved in working in the laser-controlled area



LASER HAZARDS CONTROL MEASURES

Control measure	What is it?	Purpose
<u>Administrative control Measures</u>		
Standard operating procedures	Step-by-step directions including laser-specific common precautions and definite guidelines	For operating the laser in a safe and controlled manner of the laser system
Maintenance and service procedures	Tasks indicated in the operating or maintenance manual	For daily upkeep of the accident, like
Emergency procedures	Instantaneous actions during an emergency, like turn of laser, call fire and safety, run in case of fire	To reduce the effects fire, explosion, release of toxic gas, or serious injury to personnel



HIGH ENERGY DENSITY SOURCES

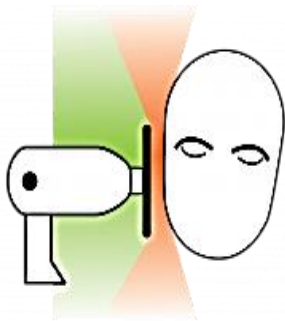
Electron beam: The various potential hazards during electron beam additive manufacturing are the following:

A. X-Ray generation:

- When the electron beam collides with a solid or gas, X-rays are produced. The majority of X-rays produced during electron beam additive manufacturing occur when the electron beam collides with the powder or substrate surface.

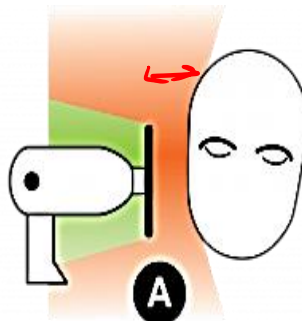
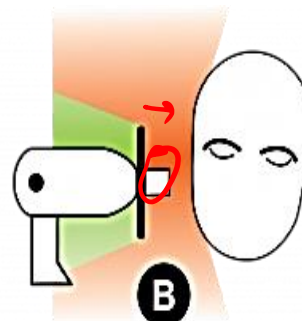
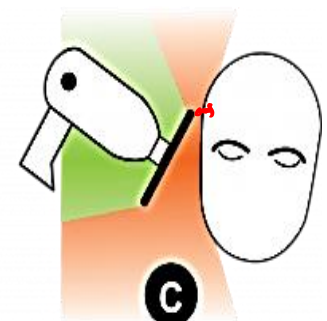


HIGH ENERGY DENSITY SOURCES



MAXIMUM PROTECTION

- Backscatter shield is close to the patient.
- Shield is positioned at the outer end of the collimator cone.
- Patient tilts head if needed to accommodate the exposure.



POOR PROTECTION

- A. Device is not held close to the patient.
- B. Backscatter shield is not positioned at the end of the collimator cone.
- C. Shield is not parallel to the operator.



HIGH ENERGY DENSITY SOURCES

B) Visible radiation:

- The melt pool is produced through the interaction of the electron beam with the powder or substrate surface. The melt pool of molten metal in the electron beam additive manufacturing process is what emits the light. The eyesight is harmed by the direct observation of this light.



HIGH ENERGY DENSITY SOURCES

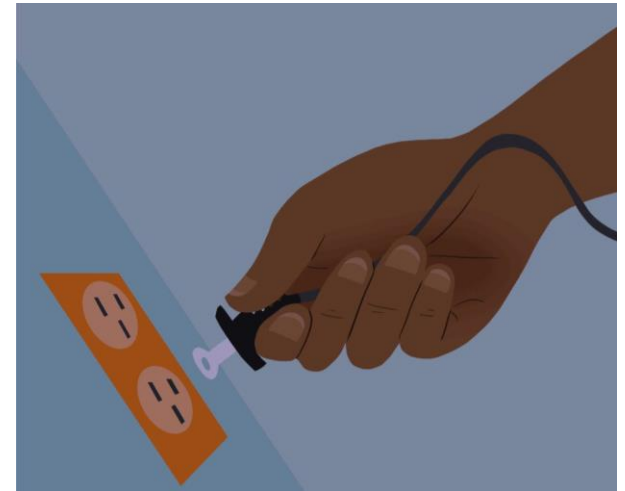
C) Vacuum:

As high vacuum is necessary for electron beam systems to operate smoothly, implosion and the potential risks of flying glass, chemical splatter, and fire can occur.



HIGH VOLTAGE

- Electrical shock risk exists when exposed to electrical components with a voltage greater than 50V.
- During installation, maintenance, modification, or repair, there is a chance that the power supply or internal components will malfunction.
- The magnitudes vary depending on the extent of the exposure, but in the worst case, it might result in electrocution death.



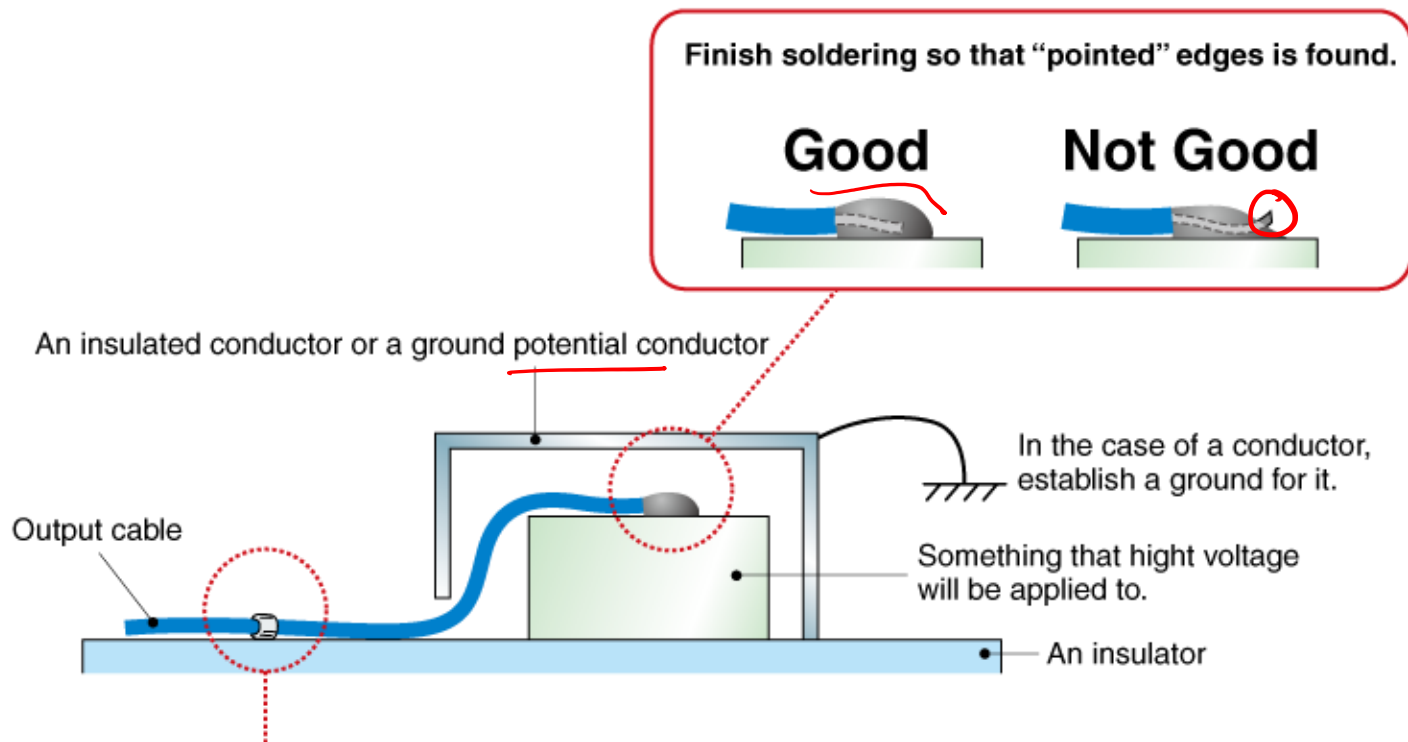
HIGH VOLTAGE

The following are some of the control measures:

- Ground all the equipment properly.
- Insulate and safeguard the electrical terminals.
- Utilize a barrier mechanism to prevent contact with electrified wires.
- Verify sure the electrical warning tags and signals are firmly in place and clearly visible.
- Make sure the "power-up" warning lights are clearly visible.



HIGH VOLTAGE



CHEMICAL HAZARDS

The sources of chemical hazards can be classified as follows:

A) Compressed gases:

- In additive manufacturing systems, a variety of gases with varying toxicity and dangers are used.

The safety control measures used with compressed gases include the following:

- Separation of personnel and the gas cylinder.
- When not in use, the gas cylinder should be stored properly (capped, supported, ventilated enclosure, segregated).
- A method for closing the gas line off and purging it after usage.
- Proper identification of the cylinder.
- Location gas detection



CHEMICAL HAZARDS

The sources of chemical hazards can be classified as follows:

B) Fumes and gases

a) Metal fumes:

- Metal fume fever is brought on by the metal vapours produced during metal additive manufacturing techniques (like influenza).
- The symptoms include a metallic or sweet taste, chills, thirst, fever, soreness in the chest, exhaustion, gastrointestinal pain, headache, nausea, and vomiting.
- It develops after many hours of exposure.
- Typically, within 1-3 days of exposure, the symptoms go away completely.



CHEMICAL HAZARDS

b) Exposure to ozone:

- Ozone is produced when metal additive manufacturing methods are exposed.
- Mucus secretion, headaches, fatigue, eye and respiratory tract irritation, and inflammation are all side effects.
- Even pulmonary bleeding is possible in high-risk situations.



CHEMICAL HAZARDS

c) Exposure to nitrogen oxides:

- Ozone and nitrogen oxides both have impacts on the respiratory system.
- Nitrogen oxide inhalation does not necessarily cause ozone to become immediately irritated.
- Some hours after the exposure ends, it could lead to an excessive buildup of fluid in the lung tissues (pulmonary edema).

Nitrogen dioxide
fumes



CHEMICAL HAZARDS

C) Hazardous compounds:

- The basic components used in polymer additive manufacturing techniques are transformed into hazardous by-products.
- For instance, acrylonitrile is one of the main breakdown products in the production of acrylonitrile butadiene styrene polymer. (ABS) (IARC)
- Styrene and 1,3-butadiene react at a temperature between 160 and 180° C.



CHEMICAL HAZARDS

Category	Potential Hazards
✓ Material Extrusion	<u>Inhalation</u> exposure to volatile <u>organic</u> compounds, particulate, additives and burns
✓ Powder bed fusion	Inhalation/dermal exposure to powder, fume, explosion, laser exposure
✓ Vat photo-polymerisation	Inhalation to volatile organic compounds, dermal exposure to resins, solvents, ultraviolet solvents, ultraviolet exposure
✓ Material jetting	Inhalation to volatile organic compounds, dermal exposure to resins, exposure to volatile organic com-
✓ Binder jetting	Inhalation/dermal exposure to powder explosion, inhalation laser, radiation exposure powders, dermal exposure to binders
✓ Sheet lamination	Inhalation of fumes, <u>volatile organic compounds</u> , <u>shock</u> ,



POWDER HAZARDS

In directed energy hazards based on specialized and binder jetting based additive manufacturing processes, the powder is employed as a feedstock material.

Some of the major health issues associated with exposure to powder are as follows:

1. **Inhalation:** Inhalation may cause upper respiratory tract discomfort.
2. **Consumption:** Consuming metal powder might cause gastrointestinal tract discomfort.
3. **Skin contact:** Skin-to-skin contact may cause mechanical itchiness or an allergic skin reaction.
4. **Eye-contact:** Contact with the eyes may irritate.

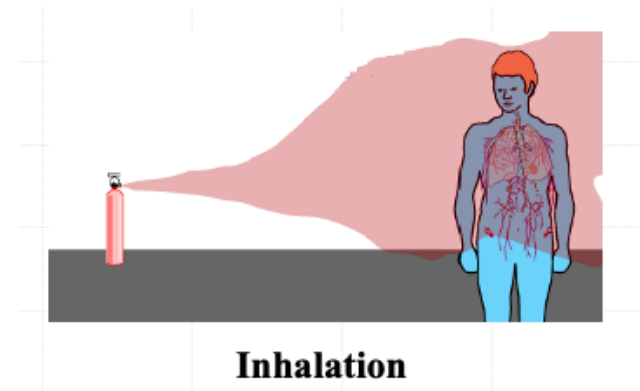


POWDER HAZARDS

The following description of first aid measures are to be followed:

1. Inhalation:

- If inhaled, the victim should be escorted outside to get some fresh air.
- In the absence of a pulse or respiration, administer cardiopulmonary resuscitation.
- Breathing is challenging, oxygen needs to be given.



POWDER HAZARDS

2. Ingestion:

- Inducing vomiting is not advised.
- After cleaning your mouth, drink a lot of water.
- If discomfort develops, seek medical attention.



POWDER HAZARDS

3. Skin contact:

- Remove contaminated clothing, shoes and jewellery and wash before reuse.
- Wash skin with soap and water for several minutes.
- Get medical attention, if irritation develops or persists.



POWDER HAZARDS

4. Eye contact:

- Do not rub the eye. Avoid contaminating unaffected eye.
- Make sure to remove any contact lenses from the eyes.
- Rinse with a gentle stream of water or saline for at least 15 min.



POWDER HAZARDS

The various precautions that need to be taken for handling and storage of powder are the following:

1. Handling:

- During handling, avoid the formation of dust clouds, use personal protection properly when handling powders and confirm dust ventilation during handling.

2. **Storage precautions:**

- It should be locked and kept out of reach of children.
- It should be prevented from contacting with incompatible materials, like moisture, flames, etc.
- The powder should be kept in the original container in a well-ventilated and fresh place.



POWDER HAZARDS

Control	Measures
Engineering measures	<ul style="list-style-type: none">• Sufficient ventilation should <u>be provided</u>, which includes appropriate local extraction, to confirm that the defined occupational exposure limit is not exceeded.• Use with acceptable <u>explosion- proof ventilation</u> intended to handle metal particulates.
Respiratory equipment	<ul style="list-style-type: none">• Suggested personal protective equipment: Dust mask generally with filter type <u>P3 (EN 149)</u>.• Where risk assessment shows air-purifying respirators are appropriate, a full face tor conforming to EN 143 (Type P 3) should be used and suitable respirator cartridges as backup to engineering controls• If the respirator is the sole means of protection, use a full-face supplied- air respirator.• <u>Change filters regularly</u>.• If <u>concentrations exceed the limits</u>, use <u>respiratory protection</u> as identified by qualified professional.

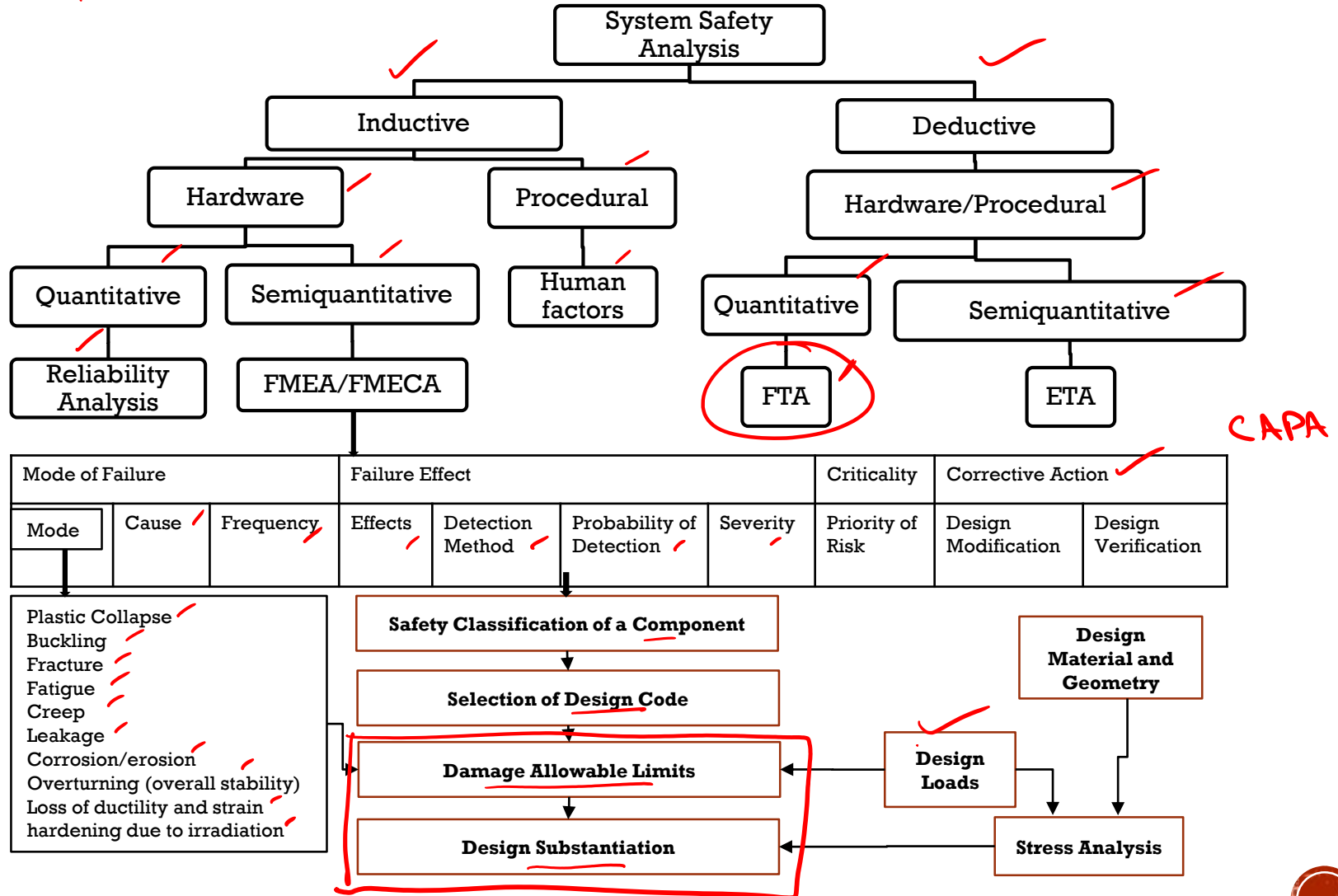


POWDER HAZARDS

Control	Measures
Hand <u>protection</u>	<ul style="list-style-type: none">• Use suitable <u>protective gloves</u>, if there is a risk of skin contact. The suggested material is <u>nitrile rubber</u>.• Consult the <u>manufacturer</u> for specific advice. Selection of the glove material depends on consideration of the penetration times, rates of diffusion and degradation and concentration specific to the workplace.• Where hand contact with the powder may occur the use of gloves approved to relevant standards (e.g. Europe: EN374) is recommended.• Use proper <u>glove removal technique</u> (without touching the glove's outer to avoid skin contact with this product).• Dispose of <u>contaminated gloves after use following</u> applicable laws and good laboratory practices.• <u>Change gloves regularly</u>.
Eye protection	Wear <u>safety goggles</u> or <u>face shield</u> to prevent any possibility of eye contact. Use equipment for eye protection tested and approved under appropriate government standards such as <u>EN166(EU)</u> .



SAFETY ANALYSIS METHODS

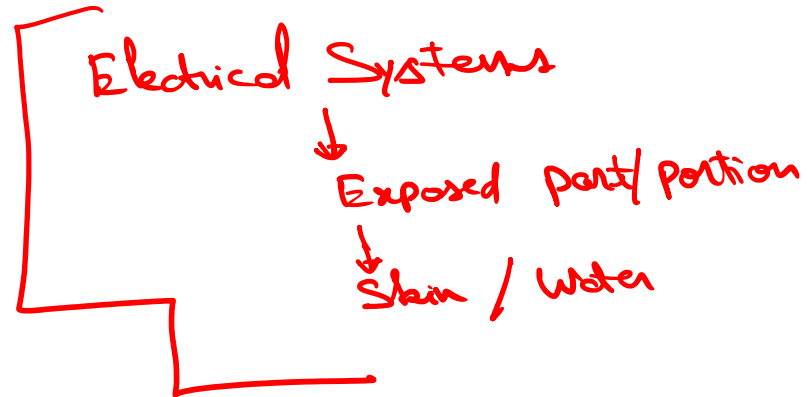


POINTS TO PONDER

- What are potential hazards of additive manufacturing?
- List the safety measures pertaining to high energy sources.
- Understand and list the safety measures pertaining to high voltage.
- Classify the safety measures pertaining to chemical hazard.
- Determine the safety measures pertaining to metal powder.



ASSIGNMENT



THANK YOU

