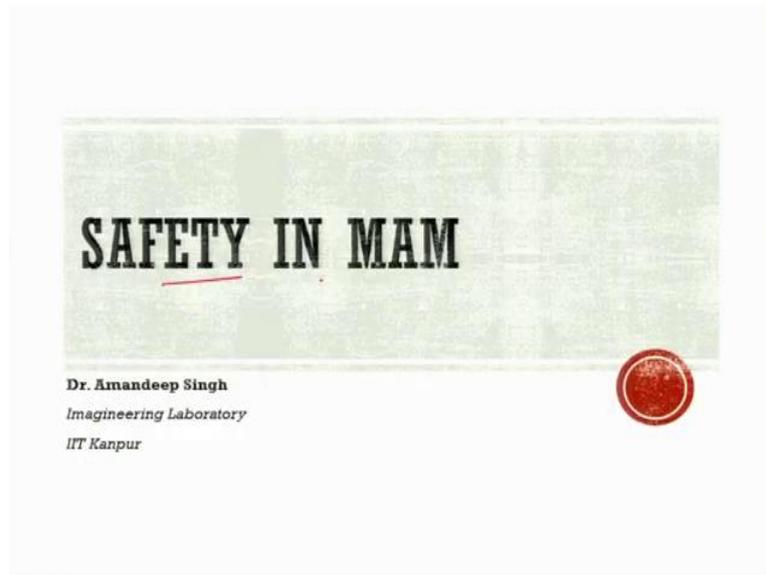


Metal Additive Manufacturing
Professor J Ramkumar & Dr. Amandeep Singh
Department of Mechanical Engineering and Design
Indian Institute of Technology, Kanpur
Lecture 43
Safety in MAM

(Refer Slide Time: 0:42)



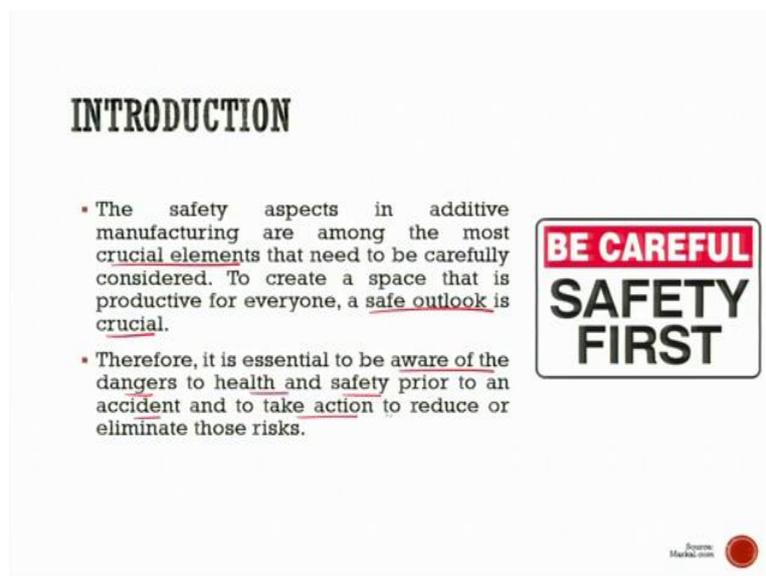
Welcome to the course Metal Additive Manufacturing, we are in the last week of the course where I will start from the safety measures or safety hazards in metal additive manufacturing then I will talk about the costing, costing methods, different models then we will talk about the Industry 4.0 and metal additive manufacturing. Finally, I will summarize the course and just try to recapitulate the things which are covered in the 12 weeks. So, safety in metal additive manufacturing.

(Refer Slide Time: 0:45)



The potential hazards in additive manufacturing, high energy density sources, high voltage sources, chemical hazards and power hazards would be majorly discussed, then certain analysis methods are there for which a table would be seen. I will try to see how the safety analysis methods are classified.

(Refer Slide Time: 1:04)



First is 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. So, due to high energy sources, chemicals, metal powders which are used in additive manufacturing systems sufficient safety precautions must be taken both in the

research labs or in the industry. 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.

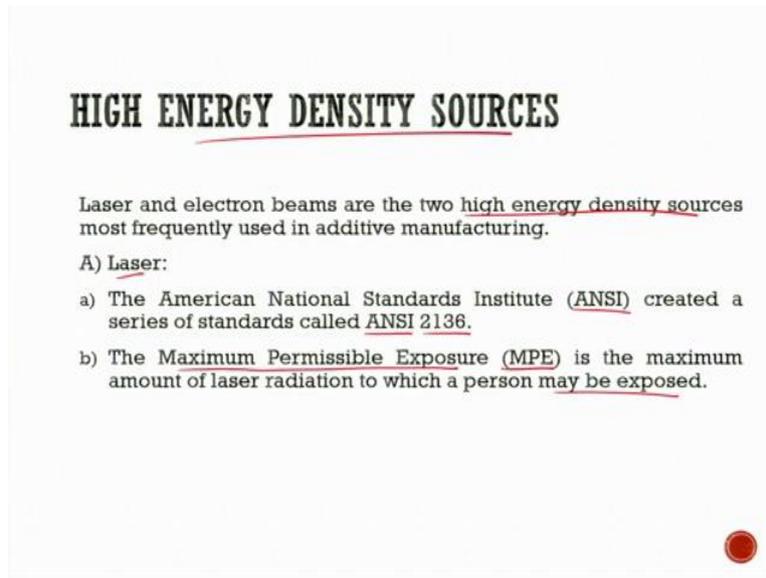
(Refer Slide Time: 1:41)



The hazards in additive manufacturing could come through high energy sources, high voltages, chemical hazards, metal powders. High energy sources might be laser, high voltage is the high voltage of the electricity, chemicals are due to the gases, metal powders might go, metal powders might be hazardous to the skins or might be hazardous to the eyes or it might be also inhaled while breathing.

So, high energy source, heating source, deposition head, material feeding system, workstation that is for task manipulation, beam manipulation system, these all components could contribute or could adverse the health of the person or could bring them in the danger in one way or other.

(Refer Slide Time: 2:26)



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.



So, laser and electron beams are the two high energy density of sources which are most frequently used in additive manufacturing. The lasers. The American National Standard Institute that is ANSI created series of standards which are called as ANSI 2136, I would like to try to show you the tables for the different standards which are there and the applications or the fields which these standards cover which pertains to the safety measures or safety standards given by The American National Standard Institute.

So, these standards offer instructions on how to use and handle various laser safety considerations. Then we have a term known as MPE which is maximum permissible exposure this is the maximum amount of laser radiation to which a person may be exposed. So, depending upon different safety considerations and laser usage these MPE standards are set.

(Refer Slide Time: 3:23)

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.



Source: Wikipedia.org

The specifics of different standards are displayed without risk or negative biological effects on the skin or eyes. The list of MPE values for the eye and skin with regard to laser wavelength and likely laser exposure period is provided in the ANSI Z136.

(Refer Slide Time: 3:40)

HIGH ENERGY DENSITY SOURCES

Standard	General description
ANSI Z136.1 Safe use of <u>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 use of <u>lasers</u> in <u>educational institutions</u>	Addresses laser safety concerns in educational <u>institutions</u> .
ANSI Z136.9 Safe use of <u>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.

Source: Wikipedia.org

But this is a table for the standard for such ANSI Z136.1, ANSI Z136.4, 136.1 talks about the safe use of lasers which provides direction to the industry, military, research and development laboratories and higher educational universities, 136.4 recommends laser safety evaluations which provides regulation for measurement of the techniques required for the classification and assessment of the optical radiation risk settings.

Then we have Z136.5 which tells about the safe use of lasers in education institution specifically, so it addresses laser safety concerns in educational institutions. Then we have ANSI Z136.9 which pertains specifically to the safe use of lasers in manufacturing environment. It is intended to protect individuals from laser exposure in manufacturing environments. The standard contains industries, rules and actions to ensure laser safety in public and private places.

(Refer Slide Time: 4:45)

Nd:YAG
200mW/cm²

HIGH ENERGY DENSITY SOURCES

- 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 :

$$\frac{\text{Laser Output (W)}}{\text{Limiting Aperture (cm}^2\text{)}} > \text{MPE}$$
 - b) For single pulse lasers:

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



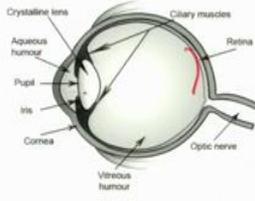
So, there are certain standard layouts for instance, the skin maximum permissible exposure is 200 megawatt per centimeter square this is for the skin, that is for and for the ocular or corneal area here as well, so this for this thing, for the Nd YAG laser these are the center, sometimes the laser emitting centers for ocular or the for the corneal area it goes up to the order of 500 nanometers or so, so lasers which are emitted at the wavelength of 532 nanometers the standards are sometimes with 2.5 megawatt per centimeter square.

So, it depends upon where the laser exposure is. So, these are the general calculations typically on a laser safety officer. The following relationship indicated dangerous, for the continuous wave laser, the laser output per limiting aperture that is which is in setting with a square is greater than MPE then it is dangerous, for the single pulse laser it is there is a energy per centimeter square, so these are the ways these are calculated or these are put into the units.

(Refer Slide Time: 5:57)

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.



Source: biology.com

So, if I try to see the ocular effect since the capacity of light to enter through ocular components in the eye varies with light's wavelength. The ocular effect of laser exposure explained with reference to the wavelength of the laser beam. The numerous eye parts are shown in the figure, we have cornea, pupil, aqueous humour, we have retina here at the end.

(Refer Slide Time: 6:22)

HIGH ENERGY DENSITY SOURCES

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

Source: biology.com

You can see here in the next figure that there are different classifications that how the laser is classified based upon the optical band light and the wavelength, so ultraviolet A, B, C classification is there which varies from 100 to 400 nanometers. So, the ultraviolet A can penetrate to the aqueous humour and absorb the eye lens.

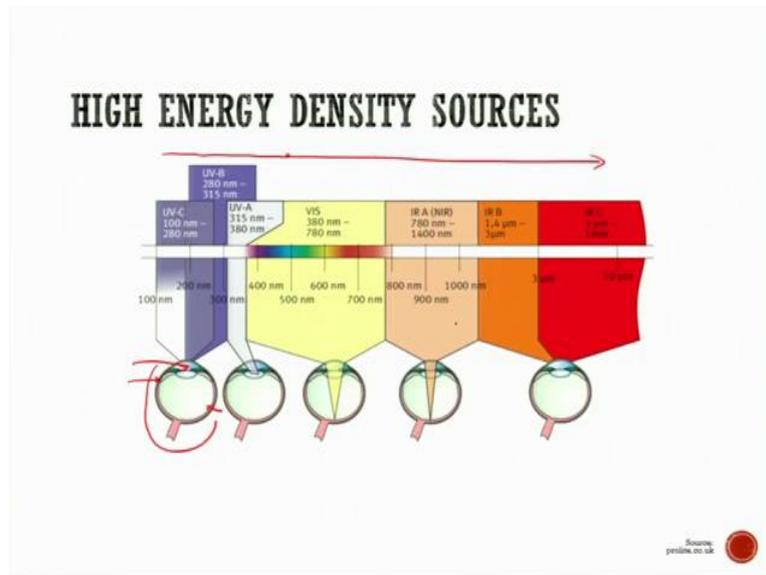
However, the ultraviolet B can absorb on the cornea and aqueous humor and cannot penetrate the iris or eye lens. Ultraviolet C light that is also used for the sanitization, the ultraviolet sanitization of the equipment which is also used in the Covid era as well. So, this can be absorbed on the cornea and aqueous humour and cannot penetrate to the iris or eye lens. So, the hazard could be the cataract or maybe photokeratitis that is welder's flash or erythema it is reddening of the eye, these hazards could come. So, depending upon the wavelength, the effect could be different.

(Refer Slide Time: 7:24)

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

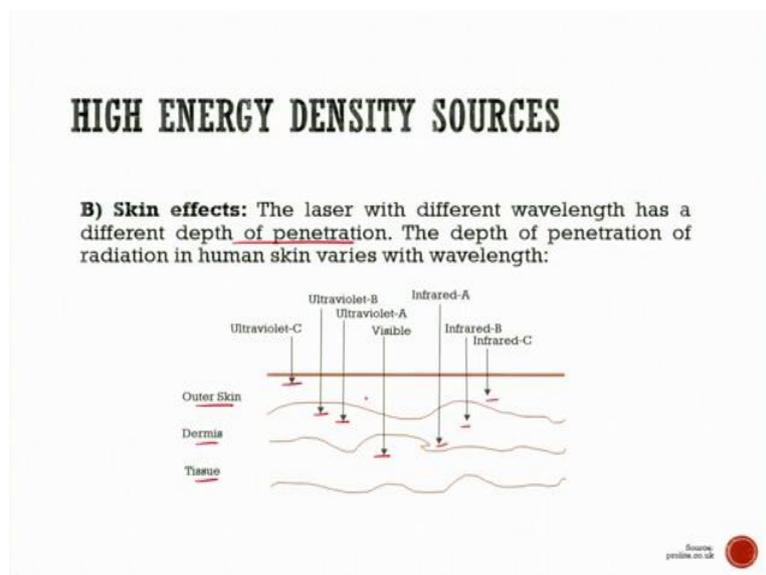
Visible light, it is highly penetrating and absorbs primarily on the eye retina, the irradiance above 10 watts/cm² can result in tissue damage. Infrared A, B, C which is of the range of the wavelength from 780 nanometers to 1 millimeter, so these are similar to visible light, will not enter or pass the lens because the wavelength is higher now but it absorbs mainly on the cornea. The effect of retina causes cataract and can result in burning and irradiance as the irradiance is high.

(Refer Slide Time: 7:58)



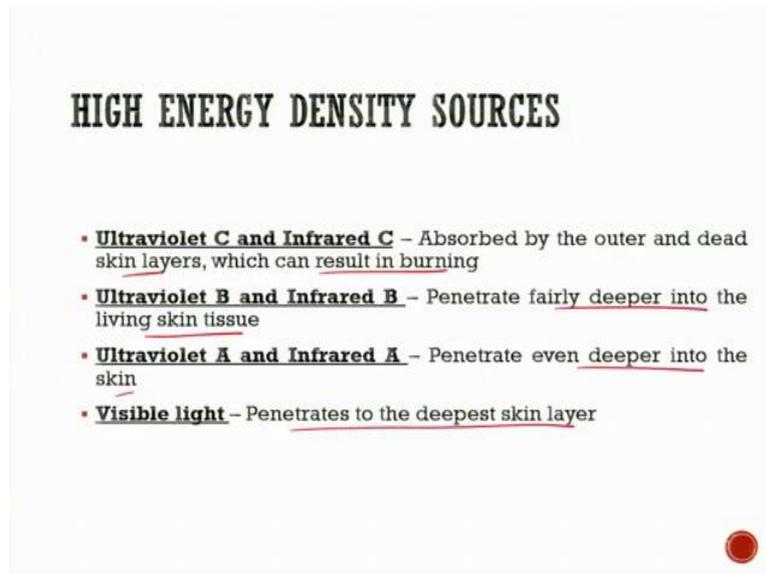
So, this is how the wavelength affects the parts of the eye but this is again an eye component, so eye means here we have pupil here, we have cornea outer here, inside we have retina here, so you can see how ultraviolet C, B, A the wavelength is increasing here and how the effect is being shown in these figures. So, to what part does it affect? It affects only here, the ultraviolet C only comes to the aqueous humour here, the ultraviolet C, B and A could only come to the aqueous humour or it can only come to the cornea part only. Then we have visible light that could be penetrating, then we have the infrared A, B, C wavelengths which could go further.

(Refer Slide Time: 8:49)



Similarly, we have the skin effects, in the skin also there is an outer skin dermis and tissue. Ultraviolet C remains to the outer scale, B goes further, A further goes, visible light can go to the tissue point as well, infrared wavelengths also just affects these levels that is dermis and the outer skin only. The laser with a different wavelength has a different depth of penetration, the depth of penetration of radiation in human skin varies with wavelength as it is shown in this figure as well.

(Refer Slide Time: 9:21)



So, ultraviolet C and infrared C absorbed by the outer and dead skin layers which can result in burning. Ultraviolet B and IR B penetrate fairly deeper into the living skin tissue. UVA and IRA penetrate even deeper. Visible light penetrates to the deepest part of the skin layer. So, this is the difference between how it affects the eye and skin but both the ways or the both the parts of the body it has a detrimental effect.

(Refer Slide Time: 9:50)

HIGH ENERGY DENSITY SOURCES

Classification of lasers

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

There is a classification of laser, class 1, 2, 3 and 4 based upon the radiation levels it produce. The laser class 1 is not capable to produce radiation levels which can cause damage. The class 2 is a visible laser that is the wavelength is given for 400 to 700 nanometer, which cannot surpass the maximum permissible exposure that is the MPE value. So, MPE time less than 0.25 s cannot be surpassed by class 2.

Class 3a and b are the lasers whose output is less than five times the ocular MPE value. And 3b is a specific kind of the class whose output is certainly less than 5 times of the ocular maximum permissible exposure but which cannot exceed an average radiant power greater than 0.5 watt for 0.25 seconds or longer or which cannot produce radiant energy greater than 0.125 joules for exposure times less than 0.25 seconds. So, this one is for the continuous, the other one is in the joules energy is given for the single pulse. Class 4 is the laser with output more than the limits of Class 3b lasers.

(Refer Slide Time: 11:20)

HIGH ENERGY DENSITY SOURCES

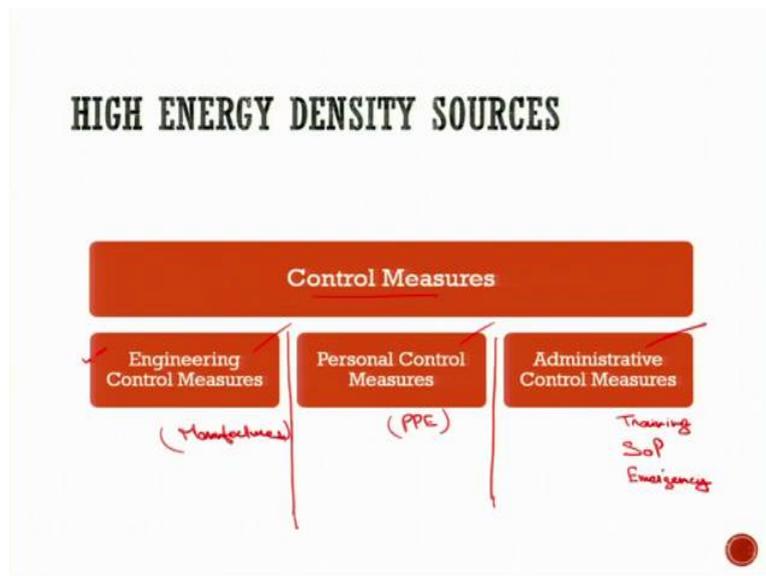
▪ The penetration results in a different effect on skin, based on the laser intensity. The effect of laser light is presented below:

Effect	Reason	Damage	Depends on
Thermal effects	Rate of energy absorption exceeds the heat transfer rate that the tissue can handle in the exposed volume	Burning	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 chemical reactions in tissue from the absorption of ultraviolet radiation	Burning	Amount of energy absorbed in a given volume of tissue
Delayed effects	Due to the absorption of ultraviolet radiation which can cause mutation in the DNA of living cells	Skin Cancer	Net dose of radiation received and whether the exposure is acute (short period) or chronic (long period)

Then comes, the penetration results in a different effect on skin based on the laser intensity, the effect of laser light is presented here, the effect could be thermal effects, photochemical effects, delayed effects. Thermal effects would be rate of energy absorption exceeds the heat transfer rate of the tissue and can handle to the exposed volume, so it can cause burning so it can cause burning, in the photochemical effects also the induced chemical reaction in the tissue from the absorption of ultra wide radiation do come and it also causes burning.

In the delayed effects, that is that does not happens immediately there but later due to absorption of the UV radiation which can cause mutation in the DNA of the living cells and these delayed effects which are not immediate could come later could also come up to the level of the skin cancer. So, this is how the energy sources affect the skin or the eyes.

(Refer Slide Time: 12:12)



So, high energy density sources control measures are engineering control measures, personal control measures and administrative control measures. So, in the control measures if we see in the engineering control measures there are measures which are integrated into the laser system or the laser system manufacturing itself which aid to protect the people against any dangers which are connected to laser usage.

Personal control measures are the people have to wear the protective eye skin protection, the PPE equipment (personal protective equipment), this is from the manufacturer, the engineering control measure then this is personal PPE used to be one. Then administrative control measures means these measures include the rules and techniques for safe operation of laser and are used to confirm a concurrence with the protocols, which are provided by the administration.

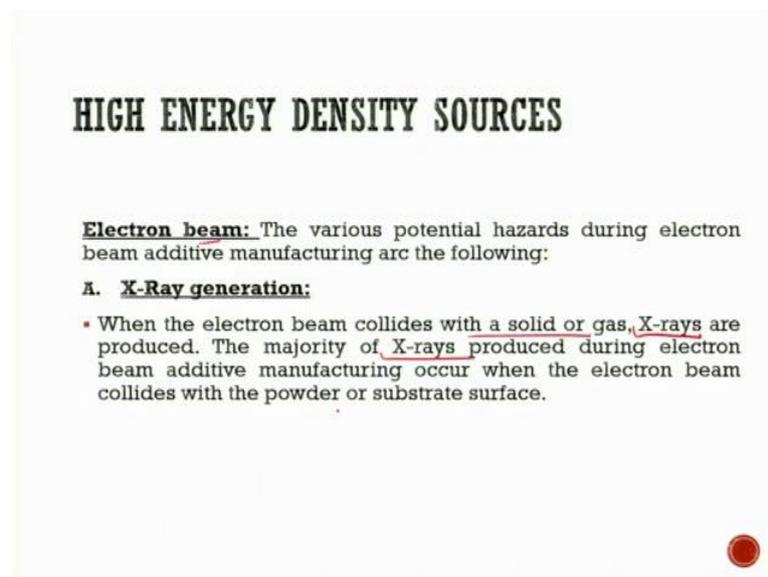
So, in the engineering control measures various setups could be made or various adjustments or the systems could be provided by the manufacturers such as it could provide remote interlock connector that is the electrical connection between the power supply and an exterior device which can be switched off or which can trigger a light or audible signal every time the neighbour is energized or so.

Then it can have a beam stop or attenuator, then activation of a warning system that is a light and loud alarm could come. Then remote firing and monitoring, warning signs variables this could be instituted. There could also be a panic button, then there could be a beam path control system, multiple things exhaust ventilation could also be part of it.

In the personal measures definitely the protective coating are required for two specific parts of the body eye and the body in general that is eyewear would be goggles, face shields, spectacles or maybe some prescription filters so this helps to weaken the laser radiation below the level of the ocular maximum permissible exposure.

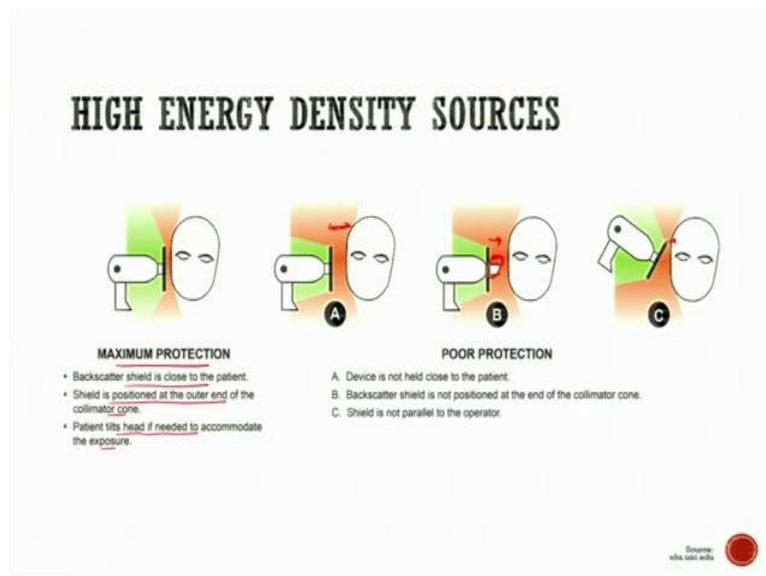
Then we have the skin protection systems in the personal control measures for example the face shields, laboratory coats or maybe cotton gloves so which safeguards the skin from the UV radiation and it prevents the skin's cancer as well. In administrative control measures we can provide training or we can provide the security and access like control over keys then we can have the SOP (standard operating procedures), which the people who are the operators, who would be working on the system or around the system would be made to understand. Then maintenance and service procedures could be there, emergency procedures are very important, emergency procedures how does it work.

(Refer Slide Time: 15:00)



High energy density sources, other than lasers could be the electron beam, so various potential hazards during electron beam additive manufacturing are could be following when electron beam collides with a solid or gas, X-rays are produced. The majority of X-rays produced during the electron beam additive manufacturing occur when the electron beam collides with the powder or substrate surface, if electron beam equipment is not sealed properly, X-ray leakage might happen and this result in the operator getting exposed to X-rays which might cause injuries.

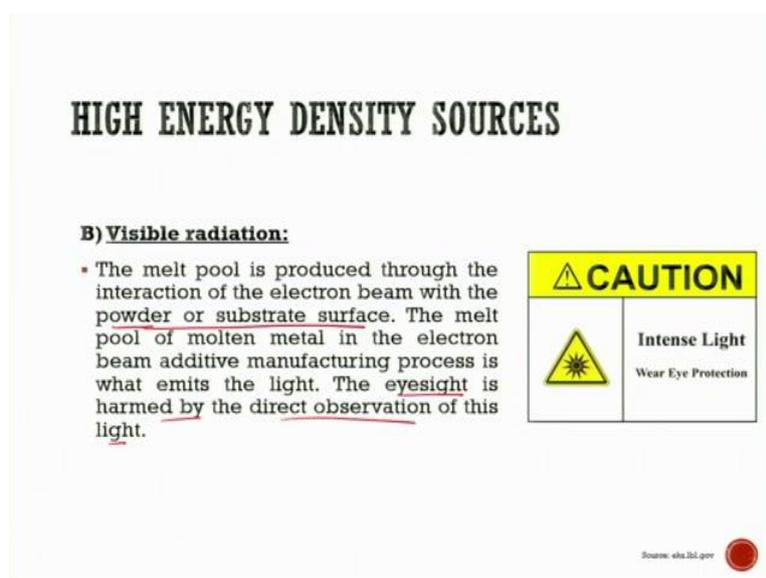
(Refer Slide Time: 15:35)



For instance there is an example showed here, this is a collimator, so this is a maximum protection that is the back scatter shield is close to the patient. Shield is positioned at the outer end of the collimator cone. The patient tilts head if needed to accommodate the exposure.

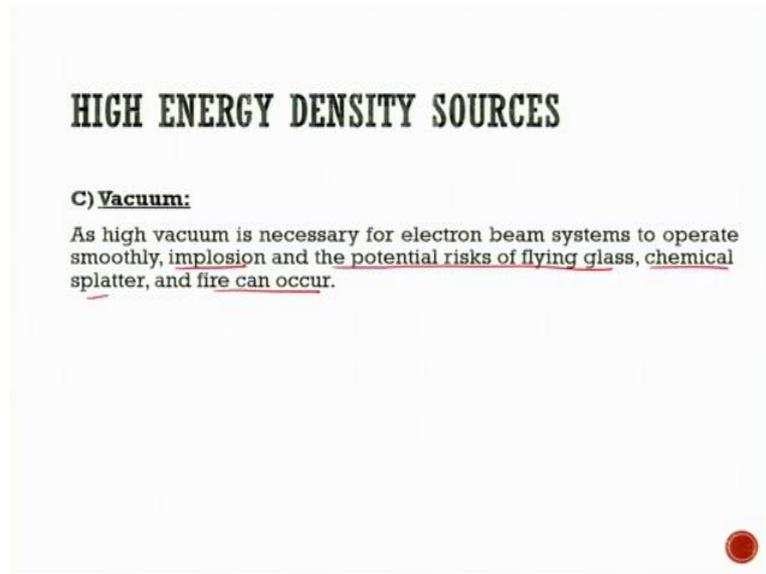
In this case the distance between the patient and the collimator is not appropriate and in this case the poor protection is there because back scatter shield is not positioned properly, so this is coming out here and in this case it is kept at angle, it can even contact the patient here, so properly setting up the system is also important.

(Refer Slide Time: 16:13)



Then we have the visible radiation, the melt pool is produced through interaction of the electron beam with the powder or substrate surface. The melt pool of the molten metal in the electron beam additive manufacturing process which emits the light. The eyesight is harmed by direct observation of this light, so intense light is there, so it is not advisable for direct viewing. So, generally the lead glass in the electron beam viewport protects people from any of the IR or UV radiations which are generated during the process.

(Refer Slide Time: 16:44)



Then we have vacuum. As high volume vacuum is necessary for electron beam systems to operate smoothly, implosion and the potential risk of flying glass, chemical splatter and fire can occur. So, sometimes implosion is actually directly opposite to explosion, so everything goes in and things can bust. So, all vacuum operators must be set up and operated with careful consideration of potential risk if this happens.

The tube ought to be in good shape that is free from corrosion or holes or cracks etcetera. So, to protect oneself from the risk associated with vacuum procedures, so again personal protective equipment such as safety goggles, chemical goggles, face shields should be worn. Ensure that no water or solvents or corrosive gases enter the vacuum system. Then one should apply a pressure to the vacuum line to prevent walls from exploding or glass equipment from blowing up.

(Refer Slide Time: 17:39)

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.



Source: [verywellhealth.com](http://www.verywellhealth.com)

Then comes the high voltage. Electrical shock risk exists when exposed to electrical components with voltage greater than 50 volt. 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 exposure but in worst case it might result in electrocution death as well.

Since industry put 2.0 that is the second industrial revolution itself when electricity was taken as one of the sources to power the machines, the protection from high voltage has always been a concern.

(Refer Slide Time: 18:23)

HIGH VOLTAGE

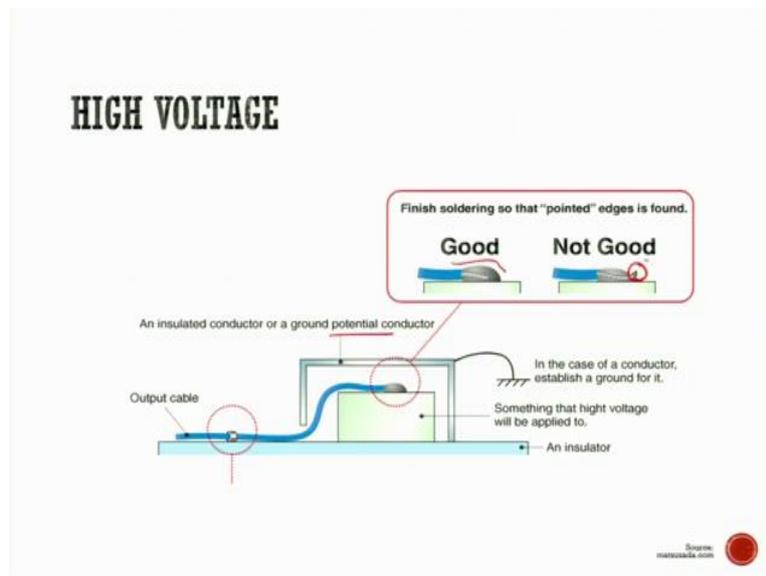
The following are some of the control measures:

- 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.



There are certain control measures such as ground all the equipment properly, insulates and safeguard electrical terminals, utilize a barrier mechanism to prevent contact with electrified wires, verify sure the electrical warnings tags and signals are firmly in place and clearly visible, make sure the “power-up” warning lights are clearly visible.

(Refer Slide Time: 18:44)



There are general things, for instance this one example is given here an insulated conductor or a ground potential conductor. So, the insulation when it happens, so this is the finish shouldering you can see the wire is completely insulated that is why it is called good. Not good means the wire is try to be insulated but still some part is protruding out, that is some leakage or some touch or contact could still happen and it could be hazardous.

(Refer Slide Time: 19:07)

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

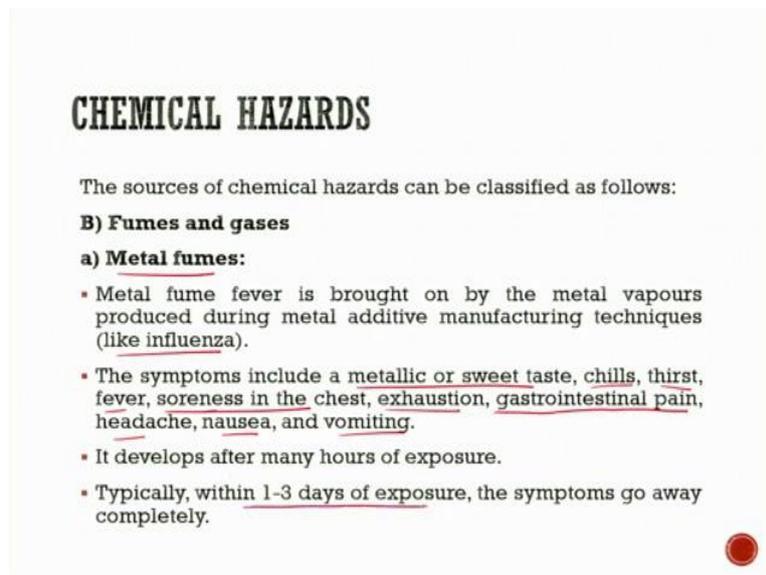


So, then come the chemical hazards. In the chemical hazards the sources could be classified based upon the compressed gases or the fumes or the exposure to a zone then hazardous compounds, first is the compressed gases. In additive manufacturing systems a variety of gases with varying toxicity and dangers that are used.

So, the gas is utilized to contain them are hazardous and can result in dangers which can be bodily dangers of high pressure which used to hold these gases. The safety control measures used with compressed gases include separation of personal and the gas cylinder when not in use the gas cylinder should be stored properly that is kept supported, ventilated, enclosure or segregated.

A method for closing the grass line of and purging it all after usage has to be there. Proper identification of cylinder has to be there, which cylinder contains what gas. Location of gas reduction system needs to be there. A rapid or uncontrolled release of these gases due to rupture of a gas cylinder can be dangerous which can cause damage or injury if the gas is toxic for example carbon monoxide or corrosive for example or hydrogen chloride which is generally used in laser systems it can burn the tissues and cause some adverse effects.

(Refer Slide Time: 20:33)



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.

Then comes the fumes and gases, the metal fumes. Metal fume fever is brought on by the metal vapors 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, vomiting. It develops after many hours of exposure, typically, within 1 to 3 days of exposure the symptoms go away completely.

(Refer Slide Time: 21:07)

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.



Source: [shutterstock.com](https://www.shutterstock.com)

So, then is 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 for the exposure to ozone.

(Refer Slide Time: 21:29)

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).



Source: [shutterstock.com](https://www.shutterstock.com)

Then exposure to nitrogen oxide. The ozone and nitrogen oxides both have impacts on the respiratory systems. 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 that is pulmonary edema.

(Refer Slide Time: 21:54)

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.



Then certain hazardous compounds. The basic components used in polymer additive manufacturing techniques are transformed into hazardous by-products. In general, in metal additive manufacturing also some compounds are produced. For instance, acrylonitrile in the polymer additive manufacturing is one of the main breakdown products in the production of acrylonitrile butadiene styrene polymer, that is in ABS polymer.

So, this ABS is classified in group 2 by the international agency of research and cancer which is IARC and it is termed as the toxic cancerous so also the styrene causes irritation to skin and eyes so material extrusion based systems release ultrafine particles or volatile organic compounds which are emitted and it also has certain health issues. So, styrene and 1, 3 butadiene react at a temperature between 160 and 180 degrees which is also not good for health.

(Refer Slide Time: 23:05)

CHEMICAL HAZARDS

Category	Potential Hazards
Material Extrusion	Inhalation 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 pounds, dermal exposure to binders
Sheet lamination	Inhalation of fumes, <u>volatile organic compounds</u> , shock,

So, in chemical hazards there could be multiple types. It could be material extrusion category, powder bed fusion, vat photo-polymerization, material jetting, binder jetting, sheet lamination. So, in different kinds of the inhalation exposure when a certain powders could be produced volatile organic compounds could be produced. In the even sheet lamination system the volatile organic compounds could be there or shocks could be there.

(Refer Slide Time: 23:32)

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.

Next is powder hazards. Powder is at various stages in different processes which are powder based, the powder is atomized, manufacturing of the powder, the use of powders, the reusing of the powder when the powder also comes in contact with the laser so there are different

stages in which the powder hazards could come in the form of inhalation, consumption, skin contact or eye contact.

So, indirect energy hazards based on the 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. Inhalation, inhalation may cause upper respiratory tract discomfort that means chronic lung diseases, asthma can both be brought by inhalation.

Then consumption of the powders, consuming metal powder might cause gastrointestinal tract discomfort, skin contact that is skin to skin contact may cause mechanical itchiness or an allergic skin reaction. Eye contact, contact with the eyes may also irritate the person.

(Refer Slide Time: 24:42)

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.



Inhalation

Source: [https://www.osha-slc.gov](#)

So, following description of the first aid measures are included. So, generally the first step is to be taken after excessive exposure to the powder is to provide general first aid, that is to get some warmth fresh air. So, as a general rule if the symptoms persist a doctor could also be consulted, so medical attention should be sought for the burns or eye injuries regardless how minor they seem but first aid and contacting doctor is required is to be there.

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

(Refer Slide Time: 25:30)

POWDER HAZARDS

2. Ingestion:

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



Ingestion

Source: jowett.ac.uk

Then is ingestion of the powders. Inducing vomiting is not advised. After cleaning your mouth, drink a lot of water, if discomfort develops seek medical attention which is in general required if ingestion of the powders happen in metal additive manufacturing.

(Refer Slide Time: 25:49)

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.



DANGER
CORROSIVE
AVOID CONTACT
WITH EYES
AND SKIN

Source: safety.com

Next comes the skin contact. Remove the contaminated clothing, shoes and jewellery and wash before the reuse of it. Wash skin with soap and water for several minutes. Get medical attention if irritation develops or persists.

(Refer Slide Time: 26:04)

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.



Source: safes.com

Next is the eye contact of the powders. So, do not rub the eye, this is the first and the foremost instruction that is given. 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 minutes. So, hold the eyelids open so get prompt medical attention, these are the certain precautions for the powder hazards.

(Refer Slide Time: 26:38)

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.



Various precautions could be taken that need to be there for handling and storage of powder. For example, handling of the powder. So, during handling, avoid the formation of dust clouds, use the personal protection properly when handling powders and confirm dust ventilation during handling.

Storage precautions for the powder. It should be locked and kept out of reach of children. It should be prevented from contacting with incompatible materials such as moisture, flames, etcetera. The powder should be kept in the original container in a well ventilated and fresh place.

(Refer Slide Time: 27:21)

POWDER HAZARDS

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

The certain powder hazard control measures which are given that is engineering measures, respiratory equipment should be set. For engineering measure sufficient ventilation should be provided which includes appropriate local extraction to confirm that the defined occupation exposure limit is not exceeded and used with acceptable explosion proof ventilation that is intended to handle metal particulates.

In respiratory equipment there is a filter type dust mask generally with a filter type P3 that is EN 149 should be worn. The certain other measures ,which are given such as the change filters regularly. If the concentrations are exceeding the limits, use the respiratory protection system.

(Refer Slide Time: 28:01)

POWDER HAZARDS

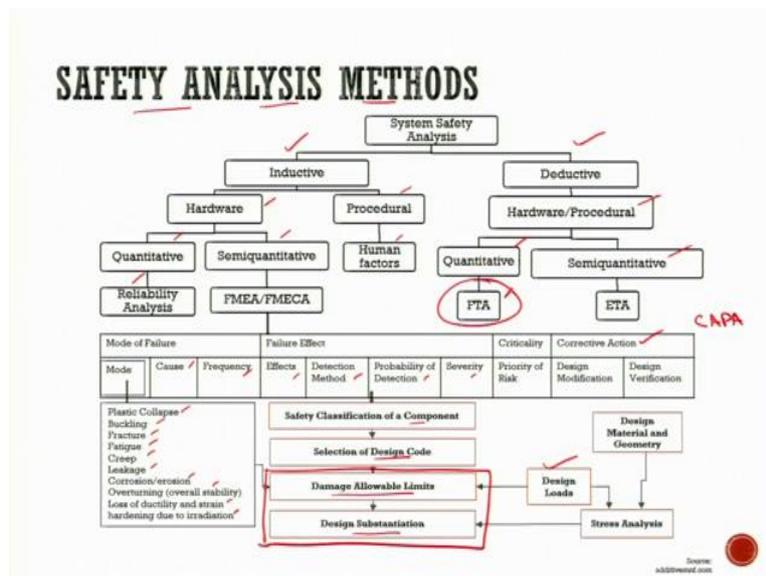
Control	Measures
Hand protection	<ul style="list-style-type: none">Use suitable protective gloves, if there is a risk of skin contact. The suggested material is nitrile rubber.Consult the manufacturer for specific advice. Selection of the glove material depends on consideration of the penetration times,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

Then for the hand protection, obviously the protective gloves are part of it, if there is a risk of skin contact the suggested material in general is nitrile rubber. So, we can also consult the manufacturer for the specific type of glove, if it is required, the selection of the gloves also is taken from the manufacturer. What kind of powders are there? and what are the potential hazards this powder could bring to the hands? and what kind of material could be worn?

Then there is a technique for the glove removal as well, while removing the gloves as well, as we have also seen in the Covid PPE equipment removal systems that the powder should not still come in contact with the skin, so there is a glove removal technique, which should be educated to the personnel who is there.

Then dispose of the contaminated gloves, disposal of the gloves after the use is very important. The changing of the gloves, at what intervals should it be changed, that is also a critical point to be taken care of. Then eye protection, safety goggles are there always, face shields could also be helpful. There are certain standards such as EN166, which are European standards which could be read and taken into account while considering the eye protection.

(Refer Slide Time: 29:12)



Now, there are certain safety analysis methods, there are multitude of methods, I am not going to cover all of them in detail individually, but in general these are classified into inductive and deductive type of the system safety analysis. Inductive means the bottom up approach, that is we start from the known causes and try to identify what could be the effects. Deductive means we know the effects already and try to seek the causes for them.

So, in this inductive we have the hardware and procedural system, procedural system was always human factors. In hardware it could be quantitative and semi quantitative system, completely quantitative system is a reliability analysis in which the performance, the probability, the environment, the time for which the equipment is working all comes into play.

In the semi quantitative, we have FMEA that is failure mode effect analysis, then we have FMECA that is failure mode effect criticality analysis in which the risk priority number that is the RPN number is put, RPN number is the one that tells us, which risk is more detrimental to overall system.

So, we can see the risk, different kinds of risk, chemical, laser, powder, so which risk is more affecting the system. So, there could be certain systems for example mode of failure, then mode could be plastic collapse, buckling, fracture, fatigue, creep, leakage, corrosion, overturning, loss of ductility, hardening so all this system could be there.

Then failure effect, then in the mode of the failure there could be a cause of the failure, the frequency of failure. So, this give me the RPN number, the failure effect, the effects of the

failure, detection method, probability of detection and severity, the safety classification of the component, selection of the design code, damage allowable limits, design substantiation, all these are there which helps us to develop the design loads.

And we can also have the stress analysis, which can also be an input to the system, which is to be designed here. Further the corrective action we better call it CAPA (corrective and preventive action), which are design modification and design verifications. In deductive systems, deductive systems means we know the effect and we are only trying to see the possible causes which could be there, the hardware or procedural system could be there, it could be again quantitative and semi quantitative.

The FTA is a quantitative system, FTA is fault tree analysis. Fault tree analysis is a tree, tree means a diagrammatic analytical technique which is used to see the reliability, maintainability or shift analysis, so this is a deductive technique in which we know the effect and only we are trying to find the causes of those.

For instance, the MPE level of the laser is higher or the people are exposed to the radiation, so this is the effect. The causes of this could be whether the protective coatings are not kept or the laser which is brought is not within the system, whereas it is the administrative cause, it is machine cause, it is the personal equipment cause, so all this system could be kept later.

Then semi quantitative is a derivative from FTA only, it is the ETA, it is the event tree analysis, event tree analysis is still diagrammatic or the quantitative technique or better it is put as semi quantitative technique in which only the event, the broader event is put, powder leak, reason one, reason two, reason three, reason one cause one cause two cause three something like that that is all.

But FTA is more quantitative, we say region one probability is this, region two probability is this, the more numbers do come here that is why this is known as a complete quantitative technique. There are certain techniques like these which could be seen or which could be employed to determine the safety of the system.

(Refer Slide Time: 33:14)

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.

So, certain points to ponder in this lecture. What are the potential hazards of additive manufacturing. List the safety measures pertaining to high energy sources. Understand and list the safety measures pertaining to high voltage sources as well. Then please try to classify the measures pertaining to chemical hazard. Determine the safety measures pertaining to metal powder.

(Refer Slide Time: 33:38)

ASSIGNMENT

```
graph TD; A[Electrical Systems] --> B[Exposed part/portion]; B --> C[Shen / Water /];
```

So, with this let us try to see an assignment, you have all the electrical systems at home, it is the electrical connections. Please try to see any exposed part in your home, exposed part or portion, if it is there. Even if it is not there please try to see whether the wiring that you have, may be for any of your equipment whether it is exposed at certain point, maybe due to some

rodent might have exposed it or some other reasons, so please try to see and try to see what could be the issues that could come.

Please only try to list the issues, okay, some the contact to skin could come or water could be there that could come to contact with the skin. Please try to list these systems only, to try to understand that how the electrical hazard systems, the tables which are given for the voltage protection so what could be there for the wires which are there you can say the safety measure is always wear a rubber footwear or always touch the wire while wearing gloves or always use a plier which is insulated, so these systems you can see.

So, this is very generic assignment that I am giving to you. With this I would like to end my lecture and let us meet in the next lecture where I will talk about the costing in metal additive manufacturing. Thank you.