Introduction to Biomedical Imaging Systems
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Lecture - 15
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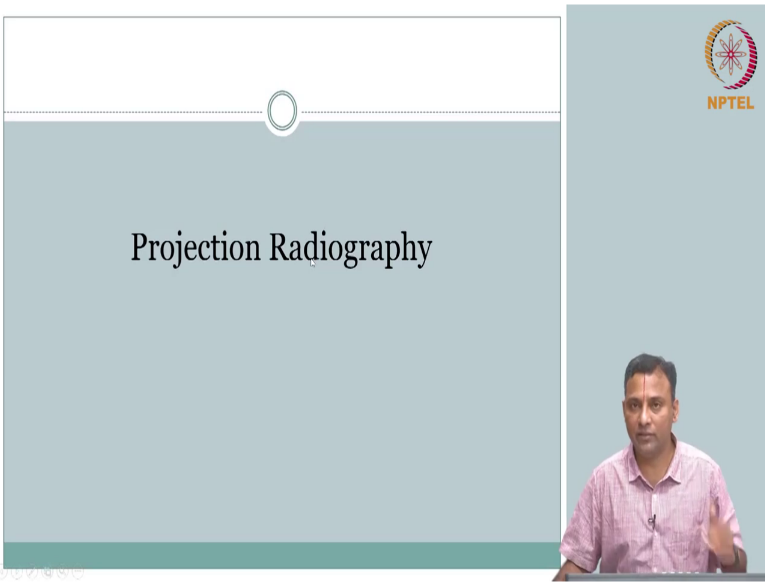

Ok. So, it is time now to move and take a plunge into the first modality that we want to cover which is going to be projection radiography. So, like I said whatever we have covered so far, we have covered the physics mostly of X-ray physics right, but I also want you that some if you take just the interactions of photons even if it is higher energy the interactions are similar.

And therefore, when we get to PET and SPECT the nuclear medicine we will only have a cursory review and some aspects that are speciality to radio activity that we ignored so far that will be covered there. Otherwise the style of coverage is going to be we recover the X-ray based physics so far.

Now, we will start with projection radiography and subsequently X-ray CT. So, these two we will cover. So, we had the physics then how are we planning to cover it? From physics we want to go to instrumentation from instrumentation we want to go to image formation from image formation we want to go to image quality ok. So, with that we will start projection radiography. By now you should be able to understand technically what is meant by projection radiography.

Projection is collapsing the dimension right. So, in our case we are going to talk about a 3D volume that is collapsed that is projected to a 2D plane that is what we call as projection radiography. So, now, you know what is radio ionizing radiation right. So, we want to talk about projection radiography is an image drawing right.

So, in projection radiography we are going to talk about X-ray projection radiography. We say projection radiography, but what is meant here what it implies is we are going to talk about X-ray projection radiography that is what happens we send X-rays through this 3D volume, how can I project this on to the 2D get a graph of based on the radio radiation that we are sending in.

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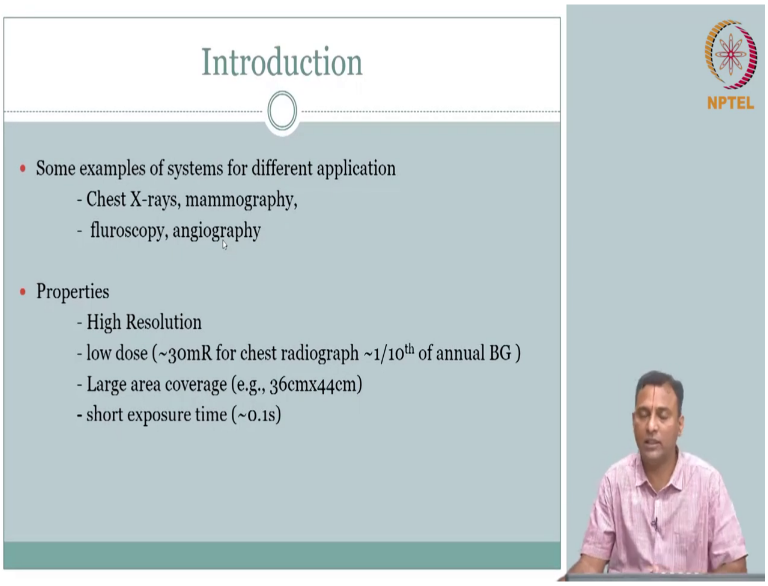

So, immediately when we talk about it we have use several examples. So, what is going to be our goal here? Our goal is not going to be cover one particular system application, our goal is to cover the underlying concept the underlying instrumentation that is there that exploits the first principles of the interaction that we talked about the physics that we understood.

So, immediately when we say what are the examples you would have probably heard's a chest X-ray which is a example that I kind of used very routinely. Because likelihood that you would have seen that system you would have been part of the imaging process you would have gone taken a chest X-ray at some point of time, but that that is one of the predominant one that you may be able to relate. But is there others that ring a bell to you have you know the other very commonly used system.

So, this is very wide range each one is specific depending on the context, but all of them are having the same underlying principle that it is exploiting which is what we will cover here right. So, chest X-ray then mammography right at least women now there is lot more awareness right for women breast cancer. So, do mammography.

So, you would have been hearing that term even though it does not say it is X-ray based you would have heard it as mammography but, essentially it is you know it is a projection X-ray modality. Then angio right you would have heard this term angio heart they want to see the vessel.

So, there is a block they do why do not do a angiography right. So, that also of course, there are CT versions of it, but essentially it also exploiting projection radiography also is therefore, quick view. Then so, cardio cancer right, breast mammography, lung infection all of these are very common you would have heard ok.

Of course, there is fluoroscopy that is also very common. So, what is the commonality? When we say X-ray projection radiography systems all of this the output is an image ok. So, what is the properties? Well, there are different aspects right when we talked about properties as in what are the common underlying features of these systems right.

We talked about some image quality aspect some radiation I mean safety aspect right those are the general requirements if you review our introduction, general requirements. We did give out some certain common general requirements irrespective of the medical imaging modality.

So, here we want to specific be more specific about X-ray projection radiography system what are the general properties of that it has good resolution that high resolution. This is something that we covered just recently with respect to dose. So, you have to have low dose you cannot dose the patient to get good image quality right.

So, low dose. So, what is the idea of what does this lower represent? We are talking about 30 milliards right. So, which is essentially about one-tenth of your annual background exposure that you anyway get. So, it is not so, the cost of doing this imaging right is very less compared to the benefit that you derive. Cost could be safety issue not the rupees or dollars right.

So, low dose. So, low dose is good right. Then large coverage area what do we mean by example of chest X-ray. A standard chest X-ray has this right you would have seen your doctor put it under the light and see until so, the there is a common size that it comes right.

So, you are able to take one shot of the chest. So, it is a large coverage area. I mean it is all relative it is not whole body, but it is till significant portion that you can get with a very short exposure 0.1 second. So, that is why I said when you go to a if you had been to a typical chest X-ray there is more time spent to make you will stand in position and he will ask you instruct do not you know stay still and all the other things.

The actual imaging after the technician goes to his room and says done right I mean it is like that. So, it is so instantaneous. So, 0.1 second is actually the exposure you now you probably know what it means right. You send the X-rays through, it goes through the body comes through the other side it gets detected, how much X radiation you are exposed to right the ionizing is very small.

You are sending it only for 0.1 second. So, in that sense he does quick right. So, these are the desirable properties. Only disadvantage is projection. What do we mean by projection? Your depth resolution is lost. Now, I use this term hopefully you are able to recognize; depth resolution is lost. What does it mean?

Resolution, resolution is nothing, but how am I able to resolve the two objects right. We talked about temporal resolution, spectral resolution, spatial resolution, this is spatial resolution, but is on the third dimension which is your depth. So, in projection radiography your depth resolution is lost. What does it mean? I cannot tell the separation between the front and the back because I am collapsing the dimension into the plane of the wall. So, that is a disadvantage.

Despite that because of the other desirable features that you see here properties this is a staple it is heavily used right. Very limited applications are actually listed here. You I mean I am sure one of the other things that you are very familiar you break a bone you suspect breaking a bone. A quick thing is they will ask you to go for an X-ray right then that can tell whether you have a fracture or not.

So, these are very commonly used applications. So, it is important we need to not worry too much about the customization for application, but there is a common instrumentation that goes behind these systems. So, that is what we will. What is a common instrumentation what does it capture of the physics then the imaging and then the quality aspects combining the physics and the imaging equations how does the quality ok.

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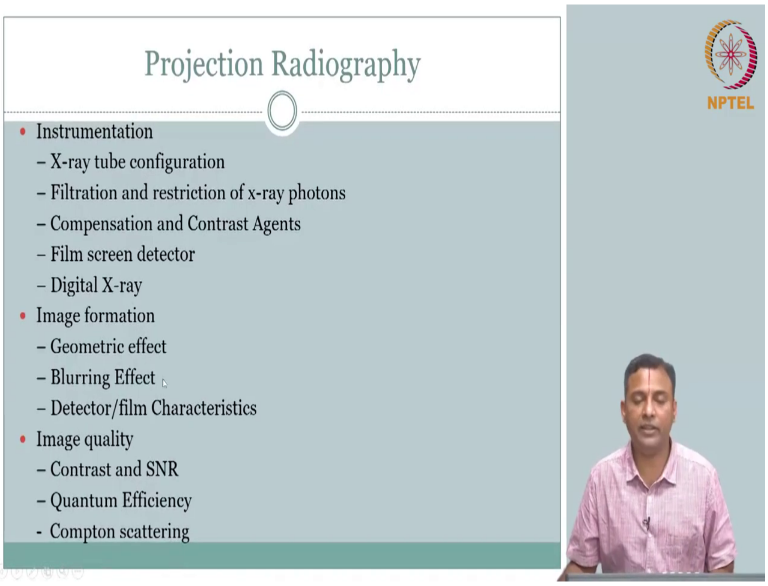

So, we will get into projection radiography instrumentation first later we will do image formation. After we do the image formation we will talk about image quality. So, within instrumentation as well we will cover only the generic instrumentation. We will not really cover the custom right, if mammography there are certain customizations that are done if it is chest X-ray it is something else.

So, we will not worry about the fine tuning. We will cover about the major instrumentation components. So, you have your X-ray tube you have some filtration, restrictions, compensation, contrast agents and then film screen detector. In fact, we will do film screen detector.

Digital X-ray is something that is now very common and therefore, we will attempt to cover this if time permits ok, image formation. So, we will get to that when we get to image formation finally, image quality all of these terms you would have seen ok. But we will get to that when we when we complete this.

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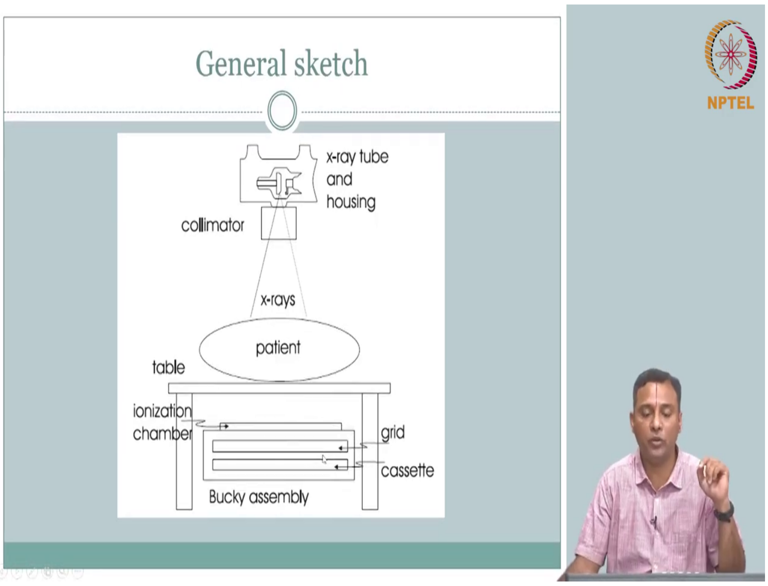

So, let us take a jump into the instrumentation. So, when I talk about instrumentation what instrumentation I am talking about? I am talking about the imaging system instrumentation. System is the complete part. What do I mean by complete part? In our case we are going to have a source that is generating the X-ray and then a patient is standing or you know lying or whatever, but then we are talking about through transmission.

So, there is a source which generates X-ray, X-ray is sent into the body and we will have to have a detection behind the body. So, it is going through the body. So, this is a through transmission setup that we are going to cover ok. So that means, what are the basic components or general sketch?

You should have a source side, you have a patient you should have the detector side these are the basic big picture right. So, you will have the source side, you will have the patient and then the detector side. So, this is a through transmission setup ok. So, now, what we will do is we will cover in the same order.

At least we will cover talk about the source first and then about whatever you see here right some add-ons and then we will. In fact, talk the imaging aspect we will cover later. But from a instrumentation point of view you know is there something to instrument in a patient right or to do with the patient based on the patient that we will cover and then of course, we will talk about the detector side of it. So, this is a order in which we will go. So, let us start with X-ray tube.

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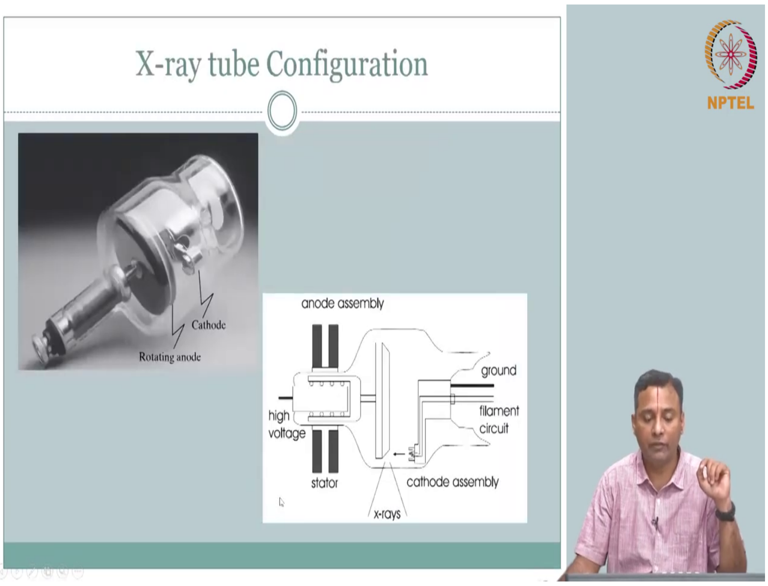

In fact, with X-ray tube right given that we cover the physics already a sketch alone tells what it is supposed to do ok, a sketch here and of course a photography. This is a photo of typical X-ray tube just for that you can appreciate that it is having a glass housing. So, you can see what is there inside right.

The details of which a captured here ok. So, what do you see? The moment you say X-ray tube configuration you get back to your physics when we talked about electromagnetic ionizing radiation particulate interactions. We talked about we are interested in using this particulate right to generate X-ray in X-ray tube.

So, we gave already some things about the working principle of X-ray tube. What you see here is a more detailed version of how that is executed ok. So, if you recall what we talked about that time is we just said there is this particulate specific particulate that we were interested is in electron.

So, you have an electron that electron is accelerated across with a voltage drop and it goes hits a anode and you have all this radiative collision right. Remember all the physics of interaction of particulate with material that we covered fine that is what is the big picture.

So, now, the question is ok where does this electron come from right. You said accelerate this electron and we designed a kilo electron volt light. So, we had electron that is going the kinetic energy is getting deposited there. So, half m v square all this we did.

So, where does this electron come from? See that is a detail right and that comes from here. you have a what we call as a filament circuit. What is a filament circuit? So, this is the cathode assembly so, on this side. So, essentially this filament circuit helps you to create the electrons generate the electrons then you have some details here right. So, the once the electron is generated it is you still see some C kind of structure here essentially that is trying to focus right.

So, you do not want the electron to go everywhere. You want to channel the electron so that it goes and hits the anode. This we studied once the kinetic energy after it is accelerated it interacts with the material, radiative, collision, all this we bremsstrahlung that we covered. So, here there are two pieces the of interest.

One is the filament circuit that is going to help you create the electrons electron cloud is going to be created and of course, there is this focusing part which is going to keep the electrons ready. So, that it can go directly hit the anode at a desired location ok. So, that was one detail.

The second detail we said it, but we will flushes. So, electrons are available here. So, the moment you apply a voltage right the electrons will move that is what that part we covered. But, what we did not cover is we have radiative and right, we talked about heating bremsstrahlung right.

So, here we just that time told there is a anode, but you see there is a anode assembly ok. So, we need to shed some light on what is there and why it is there. High voltage is not a big deal we talked about. We are going to supply high voltage to this anode that potential drop is going to make this electron right move and attain kinetic energy and hit right.

So, right so, this schematic vividly represents what are the components that are there in the X-ray tube and broadly you have three aspects. One was the cathode assembly the other is the material itself where the physics happens to create X-ray and then the anode assembly that make sure that the that tube is usable and this can be reliably produced the interactions can be controlled ok.

Of course, there is a glass housing so that it is easy to handle and it does some role in some of the aspects of filtering that we will talk about.

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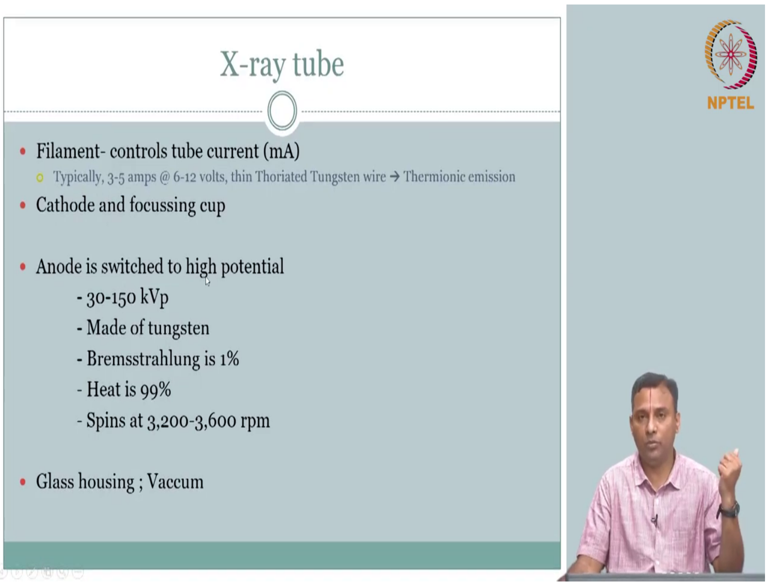

So, the film filament right the filament circuit that I talked about what does it do? It controls essentially the tube current tube. So, you have a X-ray tube. So, there is a current that is flowing through right. You have the electrons and the electrons are going to flow across a voltage. So, there is a current.

So, the filament that is there does two things. I mean essentially it controls the tube current, but in order to control the tube current when do you have tube current? You need to have electrons only then after you apply a voltage from cathode to anode electrons will move produce current right.

So; that means, the filament role is how does it control the tube current? There is this electron. So, the amount of electrons that are going to be generated here that are ready right.

So, that once the potential is applied it can move that is controlled by the filament circuit that you say filament circuit.

So, essentially the filament circuit itself typically you run through a 3 to 5 amperes of current at about 6 to 12 volts, but what is happening is the thin thorium tungsten wire. So, that is through which the filament is made of thoriated tungsten wire. So, that is a very thin material of it is there and when you pass this current at this voltage due to the resistance of the wire right the thoriated tungsten wire there is a drop in the energy. So, it gets heated up right. So, you have what is called as thermionic emission.

So, ions due to thermal energy right. So, your heat is creating ions and that is emitted out. So, that you it gives you free electrons. So, which is called as thermionic emission. So, you use this thermionic emission to get the electrons. So, once you apply this vary this you can have the electrons ready, free electrons that are just there on the cathode side it is created.

Now, the question is I want to send it to the anode. So, before we do that we have the focusing cup. So, in the cathode you have filament that creates this free electrons using thermionic emission and it has its own circuitry for that and then you have a focusing cup. Remember the C structure that I showed you is a focusing cup. So, the focusing cup helps all this electron cloud to right it allows this electron to go in the direction that you want straight into the anode surface where you want to hit it.

So, typically it is focused to the edge bottom edge. So, that is your cathode and focusing cup. Then what happens to your? So, you have what is called as primed. So, at this end of this step we say the X-ray tube is primed so that the electrons are all ready right. Now, you need to give it some kinetic energy so that it can go bombard and give you X-rays.

So, when you want to do that anode is switched to high potential. What is we mean by high potential? Somewhere between 30 and 150 kilo volt p. What is this p? That is your peak. So, that is the 30 to 150 kilo volt peak volt that is what you apply right. So, this again it has its own circuitry. You can get this voltage from the line right and then increase it amplify it rectify it and then you can get.

So, you apply a very high voltage, peak voltage in the order of 130 130 to 150 kilo volts. So, when you apply that these part you know from the physics. So, you have a anode typically made of tungsten right then you have your bremsstrahlung you have your you know heat generation collide right.

So, look at this only 1 percent produce produces 1 percent produces bremsstrahlung 99 percent is heating. So, clearly if you have this 99 percent heating lot of heat is generated. So, if you have a glass casing, so, much of heat is generated what is going to happen? It is just going to burst right, it is not sustainable. So, you have to cool it.

So, in order to cool it that is where your anode assembly you saw a straighter and there was so, rotation. In fact there was a marking in the previous slide right rotator. So, essentially what happens is this anode is not just a square that static it will rotate right. It will rotate. So, that it is always the electron is going to come and impede here. So, the thickness is going to be that electron has to go through the thickness right.

So, it is going to be like this. So, it is going to rotate in this direction. So, we call this spins at 3200 to 3000. So, there are even little more rpm’s available. So, it I mean that is a detail. Essentially what does it do? It dissipates heat by spinning fast. So, that you do not hit the same location again and again also right. So, you have the spin mechanism that is what that rotor is for.

So, with respect to X-ray tube these are the details that we need to know where we can relate the physics of how X-ray is generated with the components that are there in X-ray tube to enable this physics. This is all we will we will cover right. Again the last, but not least when you we solve house rate. So, this is a glass housing and there is a vacuum in between.

So, now, the details fine. So, this is what the construction of a X-ray tube is. So, now, getting to the operational detail because we want to use this for imaging system. What are the operational details we need to know from the instrumentation? How much X-ray to come out right who has control how do you control that right that is important question.

How long you want to send the X-rays because I do not want to fry the patient rights and bombard him with X-rays. So, how long and is there way to control that in the X-ray tube ok.

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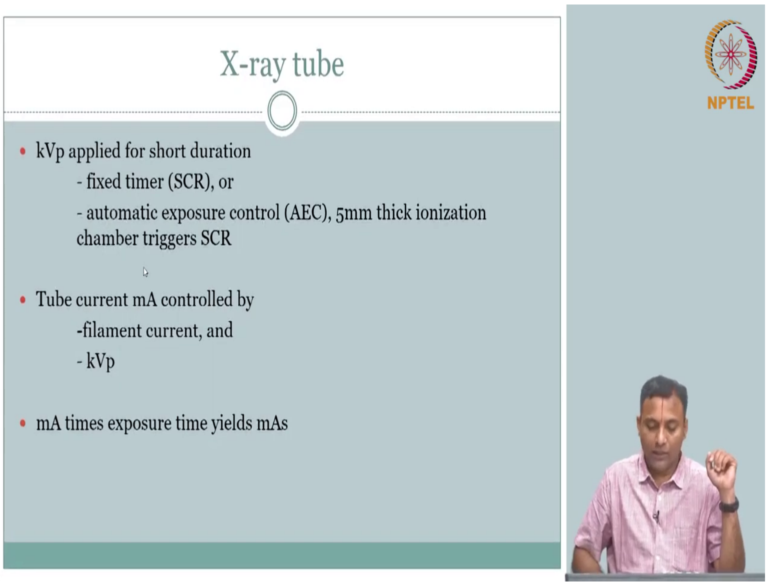

So, typically what we have is we can apply this voltage because only when you apply the voltage the electrons come and hit and X-rays come out right. So, if the electrons do not have kinetic energy it is not going to create X-ray. So, if I have to switch of the X-ray all I need to do is not apply this voltage not drive this electrons come and hit. So, that is one way of thinking about it.

So, k you know kilo volt peak is applied for a short duration. How is that short duration? So, you can apply using a fixed timer. So, you can have a control system mean you can have a silicon control rectifier on off switch right. You could you can control that and you can have a very good clock that that has a good precision to start and stop the application of this voltage that is one way to do it.

Another way to do it is well I am not in ok starting and stopping is good right. I can I know that. So, when you when you have a timer I can say open the X-ray right, apply this voltage for 0.1 second just to use the same number that we use before 0.1 second. What happens if it is we will pretend that it is all perfect 0.1 second it does, but there is going to be some latency right.

Or because of wear and tear usage maybe for the same 0.1 second the amount of X-ray that comes is not same either it is slightly more or less depending on how you did it right. So, you do not want that to be a parameter. You want to be extra cautious. You want to be safe because a patient safety is involved. So, I better be extra cautious. What I can do is I could have automatic exposure control.

What if this timing circuit fails instead of 0.1 second somehow that say rectifier got you know dysfunctional, instead of 0.1 second it goes to 1 second? It is still small time you will not know right, 1 second, 10 seconds then you are essentially frying that you are bombarding the patient so much x radiation right, you cannot do that. So, what we could do is automatic exposure control.

So, now, recall the definition of exposure. We have air, amount of ionization that happens in a controlled volume of air right. We talked about that as a exposure the ionizing capability right. So, with so, here what we can do is we could have that air chamber right. So, you could still have that. So, you can have a 5 mm thick ionizing chamber that is kept along with the patient right. So, between your exposure.

So, you could while you think this is what you are exposing the patient you have this calibration you have this automatic exposure that is decides the patient and that kind of gets a live reading of what is a exposure that is coming. So, if the exposure is high then it can trigger a shutting down. So, that is based on automatic exposure control.

So, you can control this based on measuring the exposure simultaneously when the patient is dose and that is even better right because now you know you are not relying on just the timing. You are actually measuring and saying ok this is more than what this patient needs to be exposed and. So, you shut it out. So, that is another way to do it. So, that is one control.

The other control is tube current. So, we talked about this tube current. Tube current is important right because see this electrons that are flowing in the tube right that is gaining some energy and hitting and X-rays are coming out. So, to control this tube current is important. How is this control? There are two aspects.

One is the filament current. Why? Because, the filament current creates the electrons that are ready now right during priming. So, number of free electrons that are available to charge to right available to accelerate and share their kinetic energy with the anode to create X-rays that is controlled right. Tube current that can be controlled by playing with the filament current right because that creates the electrons available and then of course, your peak kilo electron volts.

So, these two can be used to control the. So, clearly if you want to produce the X-rays it has to do with the kilo electron. So, how many electrons, what energy it is coming and hitting the acceleration. So, kilo the voltage drop and the filament control filament current which controls the free electrons available to gain this kinetic energy both dictate your tube current. So, exposure is your tube current times how much time it is open. So, milliamperes milli amperes is the current units right times the exposure.

Exposure time is milliampere second. So, this is the reported. So, mAs is a important quantity. So, the doctors typically or whoever is doing the data acquisition right they have a important role. So, they control this mAs. So, some typically in the control panel they have a control over mAs tube current ok and timing. So, they can fix one or the other clear good. So, that is with respect to X-ray tube.

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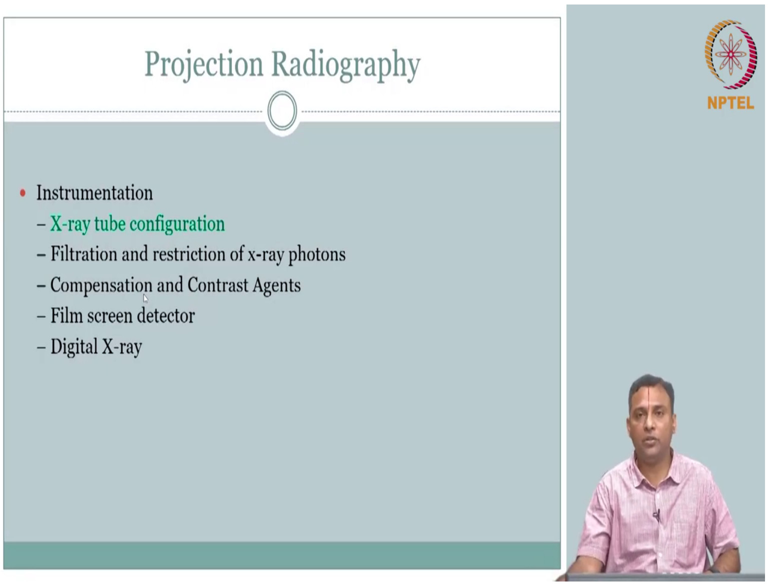

So, now what we will do is we finish X-ray tube configuration. We will quickly move towards filtration and restriction of X-ray photons. So, now what we have done is first part I know. We have created this X-ray. So, when I say X-ray just to tease you. What is coming out?. Yeah, anode is doing and the interaction takes place and bremsstrahlung right. So, that remember that curve right.

The energy increases right then there are lot of photons with certain energy and then it drops. So, the highest the k peak kilo volts kVp that you applied right, typically there you will not get photons with that energy right. So, you are going to have this hill kind of shape. So, that is your spectral that is coming out poly energetic ok.

So, you have poly energetic X-ray spectrum coming due to your bremsstrahlung. Now, the question is X-ray has done its X-ray tube has done its job, but do we want to send that to the patient directly or is there any other physics that aspects that we covered in the physics that we need to pay attention to.

So, filtration, what do we mean by filtration? I have this spectrum that is coming out. Filter means, I have to you know take out something filter out something. Here what does that mean? Filter out what? X-ray photons at certain energy level. So, before we make a intuitive explanation for this even before covering that the need for that should come to you naturally.

So, what is the need? I have this X-ray spectrum that is coming in can I just send it through the body? So, imaging systems, what do we want? We want signal and noise. These are these are what is our signal? The signal is photoelectric effect. You want to maximize the interaction. Is there a relationships with the energy and interaction? Yes. We already said if it is too little and energy right it will probably get absorbed in the material that it passing through. So, we want through transmission.

So, if you send low energy right X-rays with the lower energy it will probably get absorbed in the body which is very good right. It is interacting, but then if it is completely absorb, I will not get anything on the other side. If I say so, say if I spend low energy that means, everything will get absorbed here nothing will come out on the other side.

So, I will not be able to catch and say there is a differential attenuation that is distributed like that. Everywhere I will not get any signal right, every location I will not get any signal. Because everything is inside the body it is not coming out through the other side. So, that is not in fact, you end up dosing the patient unnecessarily or the other extreme when you send that energy high energy.

It does not interact remember our crude analogy we all the energy I go I just do not interact that I will push everybody and come through the other side. So, it will come. So, you will be able to collect those X-ray photons, that is coming through the same energy. So, number of photons that you sent pretty much you will receive the same number of photons there will not be any attenuation right.

So, I will not be able to tell about your material. So, you need filtration. Of course, we will talk about restriction. Before doing this we know we cannot send the X-rays spectrum with all the energies because that is not conducive for imaging perspective. So, we need to pick a range of energy where we can maximize photoelectric effect and have enough signal to have a signal to noise ratio that is appreciable that can give you contrast ok.

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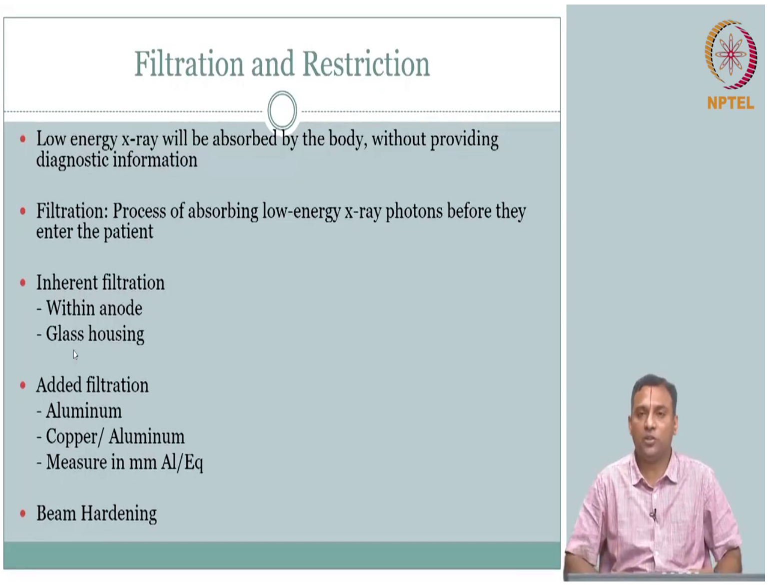

So, low energy X-rays will be observed by the body without providing diagnostic information this is what we know before. So, what does filtration do? So, filtration is the process of absorbing this low energy before they enter the patient. So, X-ray tube is sending out, but before that can reach your body I want to make sure I have some filters in place so that I can take out all these low energy X-rays.

It is better that this material that we place the filter that we place absorbs the low energy. You dose the material who cares you do not want to dose the patient right. So, you have a material that will take all the low energy X-rays and allow only the X-ray energy that is conducive for the tissue property so that you can get more signal and less noise right. So, before we go into the specific filters there are some inherent filtering also that is happening that is the without I mean that is the X-ray tube itself right.

So, that is within the anode and also the glass housing. This within the anode we talked about it before I will show the plot you will vividly be appreciate. The shape of the plot right the X-ray spectrum that is coming is like a hill. Already that time we mentioned the energies that are in the you know the lower end they are generated, but the anode itself absorbs it and so, it does not come out of the X-ray tube. We mentioned at that time, but now probably you can you know convince yourself that.

Yes we the hill shape was explained. At least of the lower end there was a loss was explained due to inherent right. The other is glass housing. What is a glass housing you have why is a glass housing acting as a inherent filter? Because see you are talking about high you have tungstens you have thermionic, so, you have lot of heat that is generated. So, some amount of vaporization happens of these material right. So, vaporization happens.

So, it comes and because glass is there it come and deposit on the glass. So, over time what happens is this there is a coating. So, there is already a coating on the glass, but over time also your you know vaporization thus allow a thin coating of tungsten to come and form a layer. And so, what happens? If the X-ray is generated it has to now pass through this material before it comes out of that X-ray tube the glass. So, low energies maybe they do not have they will get absorbed there only ok.

So, glass housing and within anode they act as a inherent filtering, but that is not in our control. I mean it happens over time it does it, but you are not proactively doing anything to it. What we proactively do is add a additional filter. So, how do I what is happening? All I need to do is I want a material to interact with this X-ray energy and get absorbed right.

So, what you can do is aluminum is a very commonly used material for this filtering purpose. In fact, it is so common that even if you use another material you will report the thickness of the material. See material when you say aluminum you say you know the material. So, now the only aspect that determines your attenuation, what is that? e power minus mu delta x.

So, thickness and the material property your mu together they determine the amount of attenuation. So, if I want to attenuate the signal right go recall our explanation on half value layer thickness and so on right. So that means, I want a material which can absorb the X-ray energy that is coming out on the lower end and when you mean by attenuate completely absorb and attenuate completely. So, that the other side it does not come through it has to have minus mu delta x.

So, when I say a material it has a mu. Now, the only thing is delta x. So, that is your measure in thickness. So, equivalent thickness is always reported. So, aluminum by far is the common. So, 1 2 millimeter thick aluminum sheets are kept in front of the X-ray tube to observe the low energy. If you do not want to use aluminum say for example, sometimes copper is used.

If you want to use copper that is fine, you can get the equivalent thickness of copper right because the density the mu is different for copper. And therefore, if it is less than aluminum you will have a thicker copper, if it is greater than aluminum you will have a thinner copper, but the idea is you want to filter out. So, but you report it in terms of equivalent aluminum thickness ok.

So, this is a very common way of doing it. So, the concept is very simple; e power minus mu delta x that is all. So, if I know my mu whether it is copper or aluminum or whatever material if I want my delta x needs to be changed, so that I can have how much filtering I want.

If you want 90 percent of that energy to go down you know what is your half value layer calculation right, 0.693 by. So, you know the material you can calculate how much thickness is required before it goes down by 50 percent. So, you can then say ok, I want 90 percent to go. So, come up with a equivalent and thickness ok. So, that will be used here that is so much for filtration.

In the process what happens? I just want to spend 3 seconds on this because you know this by now. First time I showed you beam hardening was in the artifact. I said this is a little difficult to understand. For now motion artifact is easy, detector going bad is easy, ring artifact is easy. There was a beam hardening artifact. I said maybe you I will talk about this when we get there. Maybe you will be able to explain this yourself. To top it in the previous lecture we talked about beam softening.

So, can you now tell to yourself what is beam hardening, what do you expect beam hardening to be? So, I have beam which is the X-ray energy that is going in right that the hill that we talked about. So, now, what have you done because of filtering? I am basically taking out the lower end of the spectrum right.

I am taking the lower end of the spectrum. So, now, what will happen to the mean energy that is coming out? So, if you have the hill there is a mean value right. If I preferentially take the low side now I take the mean what is going to happen? The mean energy level is going to be higher than before right because the low energy photons are removed.

So, you have so, many photons, but all of them are on the higher energy side. So, the average of that is going to be greater than when you had low and high and having a average this is going to be secured right. So, you are going to have higher. So that means, beam energy is increased the average beam energy of the spectrum that is coming out after filtration is increased hardened right.

When it was decreasing where it will decrease? It is called beam softening. Go, check back where we talked about beam softening, it was last lecture or the previous one. The energy was reduced the average energy was reduced it was moving towards the left that was softening, this is hardening ok.

So, this can happen not just by the filter that you are putting. It happens it could happen also within the body. So, if you have layers where suddenly you have a layer that absorbs way more than right the neighbor or the front or back right neighbor in the depth direction or front or back then what is going to happen? There is going to be a beam hardening.

So, you are sending this spectrum. I hit a very high. So, I have a just for argument ok not natural just for arguments somebody there is a bullet there is a implant there is a metal something is there right. So, if I go there is a rapid right. There is going to be different there is going to be more absorption.

And so, the spectrum that is in front of that metal and the spectrum that is coming out of the metal to probe through the other tissues are different right. The beam is hardened after going through the that material right. So, you could get beam hardening artifact because of these things ok.

So, you know where it is coming from. It is due to filtration effect. We are mostly listed filtration from the outside, but it can also happen inside depending on the material ok. So, so much is good. So, this is fine for filtration with respect to energy. What is restriction?

I go for chest X-ray right I go for chest X-ray. I better get only my chest exposed. I do not want my head right, arms, legs why should that get exposed, why should I am not interested in imaging that why should give dose to that. So, restriction is going to be essentially just before going to restriction let us just complete this.

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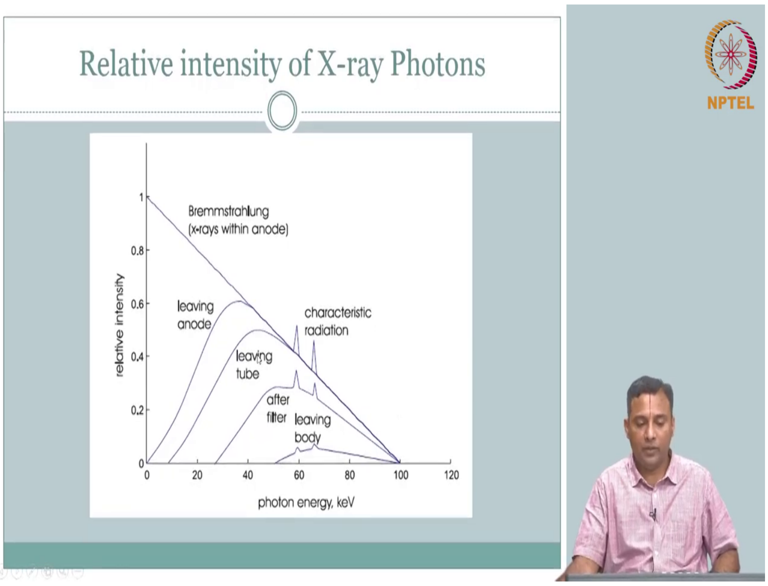

I told visually just to spoil your imagination right. This is the same thing that we saw before the hill. what is new in this is the previous time we saw this hill we had different kilo electron volt. So, there were several hills, but each one was for different applied voltage whereas, here you see different hills not because of that. You see different hills or the spectrum after each process that we have covered so far.

So, this is your theoretical. Bremsstrahlung creates X-rays within the anode starting from 0 energy till whatever maximum you have applied kilo electron volt right. So however, because so, this is what is actually generated, however, before it can leave the anode the lower energy right these things are absorbed by the anode itself right.

So, progressively what is leaving the anode is not having low energy. In fact, number of photons with low energy is less and only X-ray photons that have higher energies are leaving the anode right. So, this is at the anode, but then after anode we talked about internal filtering right. So, you have the X-ray tube.

So, this is the one that is leaving the tube. So, this already less all lower energies are filtered due to the intrinsic factors right. So, this is the shape of the energy spectrum that is coming out. Now, we have added the filter ok. So, when we added the filter again we have shaved off filtered off low energy. So, we are preferentially giving only from 30 starts with there about 30 it goes up and then it goes down.

And then this is a leaving body. So that means, it is going into the body. This is the spectrum that is after the filtration. This spectrum is going inside the body. Inside the body; obviously, we are interested in attenuation right, interaction we are talking about mu. If it is completely 0 then there is no use that is the whole idea. We try to remove the low energy.

We need to get a spectrum outside the body, otherwise everything is lost inside the body. So, once we sent 30 to actually 100 is just for writing purposes, but there very less photons right. So, when you have 30 to 100 kilo electron distribution that is sent. What is leaving the body? Only this is leaving the body about 50 to 100 right. So, all of so, you can see there is a differential attenuation that is what is exploited to see the body.

So, we have different mu's in different regions different tissues. So, I send this spectrum, it leaves that spectrum if you get some signal in these energies. So, based on this we need to talk about what was the attenuation distribution in the body. So, you see the energy how it is changing. So, that is why I said this plot is a very important plot because it kind of tells the summary of what is the signal, what is the signal quantity and the range that you are talking about in X-ray physics for imaging purpose ok fine.

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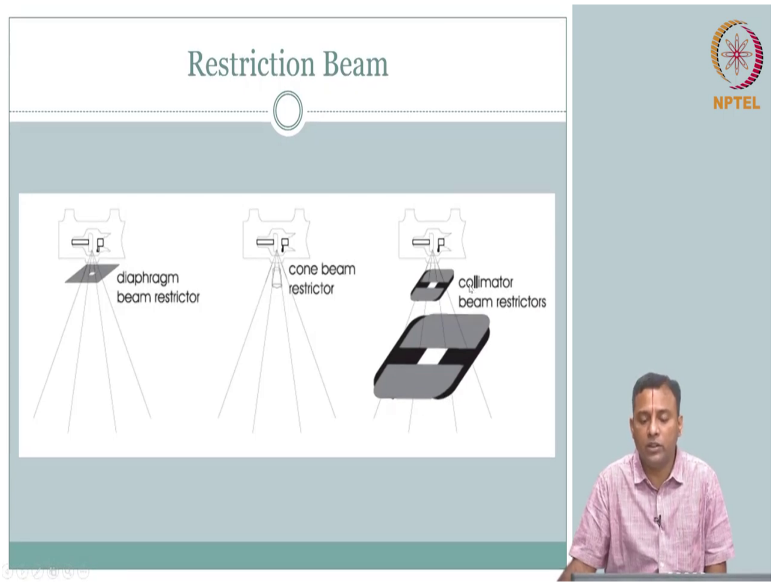

So, now we will just quickly talk about restriction. Restriction is essentially to all this is fine with respect to energy and how it goes in the filtration is fine, but then if I go for a chest X-ray I better send the X-ray only through the chest. What is a point I am sending through the head or arms or legs right that is the logic.

So, what can we do to restrict it? The same logic, is so, for example, let me try this. I do not know how well it will come. I have a torch right. So, ok so, I do not know how clear it is, but then ok. So, let me try this right. So, I get a so, I have a field of view right. I am trying to hit my pocket right.

I want to hit my pocket or more microphone right. I want to do this, but then microphone is so small, why should I hit everywhere else? So, what I can do? I can right filter everything out, but then have a small opening. I have a small opening that will exactly allow me to shed light on the microphone only right.

Why should I eliminate the field of view from this is wider right, it is wider than the microphone that I want to eliminate. So, why should I eliminate the other regions? What I can do is restricted. So, I can attenuate the other regions and have a small opening so that only the field of view is eliminated right.

So, it did not it does not come out well here because it said. So, usually I do this in the class we have a overhead you have a projector. So, it is actually a through transmission. So, I could introduce try this play with this, but unfortunately here I have a camera system, it is not through transmission. So, when I try to do this you know my object is blocking the camera side of it the detectors on the front side right.

So, yeah so, its, but I guess you can it is fairly intuitive that you can try it yourself as well. You can try it yourself as well to get the big picture ok. So, essentially what we talked about is X-ray tube it is coming out usually it comes like a cone right. All directions source is a small region.

So, when it comes out it opens up in all directions like this. So, it will be like a cone that when it comes out. So, you can have a diaphragm beam restricted. What is a diaphragm being restrictor? Essential example that I showed, you can have a led or whatever sheet where you have a small opening.

So, rest of the places it will get absorbed. Only the opening will allow the restricted field of view. So, this should be your field of view otherwise. Now, by introducing this I have a small opening. Only the field of view is restricted, rest of the places it will be absorbed right.

So, that is very simple straightforward, but the challenge or the limitation is you can have only one size right. It is very custom. Like as you could have a cone beam restrictor. So, you could have a cone shaped right. So, you can move this front or back. So, it has some advantage compared to diaphragm, but still the most popular one is your collimator beam restrictor.

You have two of them. So, you can actually adjust the slit size the opening and you can also adjust the front back. So, that you can change the field of view right more in a more flexible fashion the concept is same. Again your this aperture is opening the rest of the material will absorb and not allow to go. So, the opening is fixed here. Here you have opening that can be adjusted not only that you have two of them that gives you little more flexibility. So, I can in a graded fashion I can do right.

So, this gives you little more flexibility. By far this is the most common restrictor right collimator. So, this term collimator, we did briefly mention, but we will talk about this even more when we talk about the detector side of it. Collimator means its sending in one direction. It gives you the direction the field of view right where you want, it is able to direct it in the direction.

So, we will stop here. We have covered filtration and restriction. The next part is going to be your source side is almost done right X-ray tube filter. So, you are ready now to send this to the exact field of view you want with the exact energy that is likely to give you a good interaction and good signal they are ready.

Now, is there anything to do with a patient or can we just talk about detector right? We are talking about instrumentation. So, there is one little step that you can still do before you get to the detector details with respect to customizing it for the patient which is what we will do.

So, customizing it for the patient, the instrumentation that is used to customize based on the patient and the detector side we will cover in the next lecture. So far we have covered the instrumentation on the source subsystem. The next lecture, we will cover the remaining part and that will complete the instrumentation aspect that we wanted to cover.

Thank you.