Introduction to Biomedical Imaging Systems
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Lecture - 14
Radiation Dosimetry

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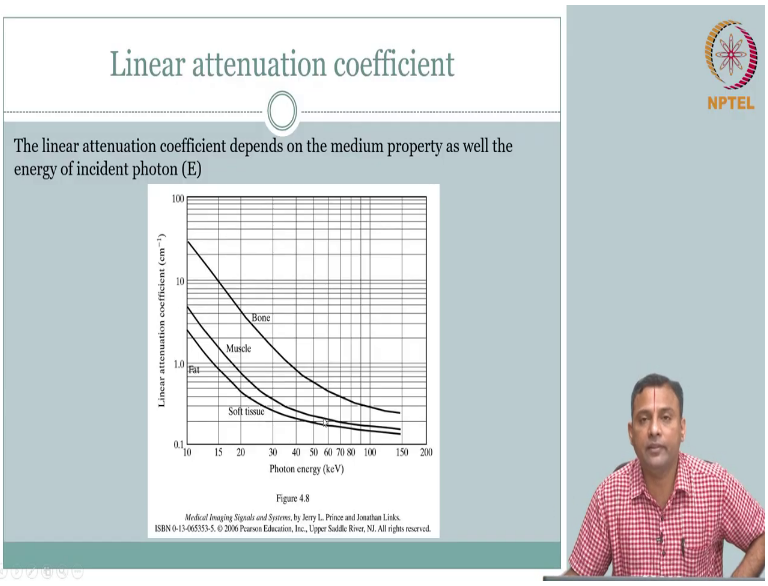

So, we covered the narrow beam mono energetic case right. We got the equations, but then I am showing this plot right which has one of the axis to be photon energy, the other is your linear attenuation coefficient and this is done for different material. So, we covered a single slab or when you have multiple slab stacked together right and then we covered mono energetic case that is it has only one energy that is coming through.

So, then I go on to show this and you notice that there are multiple energies and the mu is actually a function of energy right. So, just go back to brush up the interactions that we talked about right photoelectric effect, Compton effect and we said that time that intuitively one would expect if it is going with high energy right it will not interact much it will come out the other direction that is what we kind of we put the direction directly proportional to right.

So, what does that tell? That means, the there is signal loss right the photon energy is not induced whatever goes in comes out without much interaction. The interaction if it is photo electric it gets absorbed. So, energy is lost right the h mu's are lost and the which is your attenuation.

So, clearly this says that if I give send X ray energy that are on the higher energy side, then the difference between the different material bone or muscle or fat right the difference between them reduces just join this relate this back to when I say difference I have different material and the difference. What concept should come to your mind? Contrast.

So, the inherent contrast right between bone, muscle and fat contrast in terms of their attenuation capability, attenuation coefficient, linear attenuation coefficient reduces as you start to use higher energy. So, clearly you can see that you may want to use lower energies where the separation between them is larger, but then the challenge is you are using lower energy that is good.

But if you use too lower energy what is going to happen? You send the photons everything will get absorbed in the body, I will not get much it will attenuate it completely then I will not have any signal to detect. So, there is always this problem right. So, if it is too small yes, the separation between them the inherent contrast could be exploited, but then it will get attenuated and you will not get any photons to do the measurements right.

Whereas, if it is too large, if it is a high energy, then the attenuation will be less, So, you can start to get the photons on the other side through transmission but then there will be minimal interaction. So, you will not really be able to interrogate and differentiate between the different issues.

So, the take home message in this slide this is very powerful slide mu is a function of energy. So, the material when you say a material has a attenuation coefficient it is given that it is not just one value, it has a attenuation coefficient at that particular energy level ok. So, that is becoming the one of the additional variables in.

So, in reality, so, what we covered? We had a narrow beam case, mono energetic and then we talked about when you have one material and then you have inhomogeneous material right slabs. So, now, what we need to appreciate this? That means, we need to update our equations to account for this guy right.

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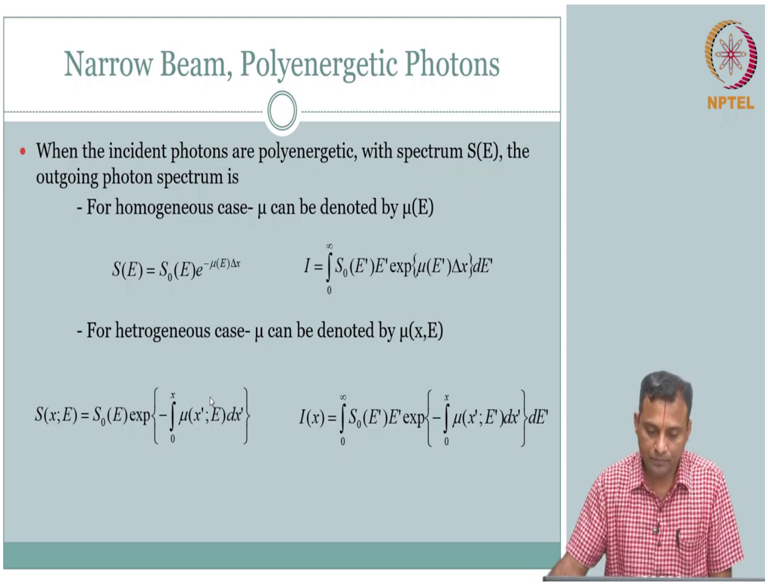

So, now what we will do is, narrow beam, polyenergetic photons that is when you have the photons come by right. What is the X ray tube doing? Bremsstrahlung. So, it you are what are you getting? You are actually getting spectrum right S of E different number of photons each photon having different energy level that is what you are actually sending in. What we covered just now is mono energetic.

So, we just did h mu and done with right, but now instead of saying n photons go in instead of that, we should be able to say there is a S of right the spectral lines remember n 1 photons at energy one, n 2 photons at energy two right. So, S of E right number of photons at different energy levels that is going in a spectral line is going in right. So, when an incident photons are polyenergetic, with the spectrum E S of E right. So, instead of sending one photon with one energy in and me receiving it on the other side.

Now, I have a spectrum of energy. So, n 1 photons at one level, n 2 photons at another energy level. So, I am sending this whole spectrum into the body different energy photons with different number of photons with different energy levels right. So, it is going in. Now, the question is if this goes in what is the attenuation? How does the material interact with this spectrum so, that you can comment on what is the S of E that is coming out?

The mono energetic case we said n photon goes in n dashed comes out and n dash minus n is your minus small n which is lost and then we wrote the at a fundamental law right. So, here S of E goes in, S of E dashed comes in or S dashed of E dash comes in whichever.

So, now, we need to relate what spectral line that is coming out going through the body in terms of the material property which is your mu, but now we will denote that as mu as a function of E. So, each energy has the material behaves differently. So, mu is a function of E ok. So, S of E is the spectral at any location S 0 of E is a spectral that is sent in right n equal to n naught remember so similar.

So, we are just updating that with S of E equal to S naught of E equal to exponential decay the same law holds good, but now instead of writing just mu delta x, we are writing mu of E. So, it is a function. So, for each energy level this holds good. So, when you send a spectral, we will pretend that the material each one is behaving independently. So, net sum is what you are getting ok.

So, it is a direct extension of your mono energetic. Now, treat this as a poly energetic case is nothing, but same behavior for mono energetic, but you have multiple energies right which is given denoted by S of E spectral lines. You can also write your intensity counter part. So, I is whatever goes in right S of E dashed and your number of photons.

So, this is your number of photons spectral line gives you number of photons at that energy level E dashed into the energy of each photon right at that level. So, that is your same definition that we did before only contextualizing here exponential of mu of E dashed, that particular E dash that you are considering of course, it is over a delta x.

The slab even now has only one right we are not really worried about that right now. We are taking one slab, but what happens when it is hit by multiple energies or polyenergetic source ok. So, now we can extend the two heterogeneous case. What do we mean by heterogeneous case?

This mu right depends on the x also remember that is what we did. So, there is slab 1, slab 2, slab 3 or at x 1 you have mu 1, x 2 you have mu 2 right. So, when it goes in we updated that equation. Now, we could do the same equation that we had for mono energetic heterogeneous case, but only now we will have to update this mu with energy. So, mu of x comma E you go back and look what we did before in mono energetic heterogeneous case.

We would have just denoted it by mu of x that is the attenuation is a function of which material you are sitting in slab 1 and slab 2 are all stacked along the x direction. So, when you move along x direction your mu changes, that is what we denoted by heterogeneous before. Now, not only that we are saying it is also a function of energy right.

So, we will update the equation, make it more complete by substituting mu of x comma E. So, your S of x comma E at any x what is come the spectral line that is present at a particular energy the spectral line at x is nothing, but the spectral line that goes in after exponential decay until that point 0 to x of mu of x dashed and E ok.

So, this is a more complete version and of course, you can write the counter part of the intensity by taking for number of photons into energy per photon that is this denotion and updating this with the two variables that are there clear. So, as much as it looks complete right you can already sense that this becomes complicated. Complicated at least from a mathematical tractability to write all this and visualize it is becoming cumbersome, let me put it that way.

So, then what do we do? We will say that ok this is complete, but you know for convenience maybe this is not needed what we could do is use our effective energy concept right we did that before. So, if you have multiple energies instead of doing it for all energies we could say this instead of calling it as a spectrum, we could reduce the spectral lines S of E to a single energy case by finding the equivalent right.

So, essentially average of this spectral n 1 into e 1 plus n 2 into e 2 by the thing right we talked about this in fact, we did an integral. So, equivalent is what we talked about right. So, if you do that then you get the same expression for mono energetic case, the fundamental law in the previous lecture.

You can use that to a very big deal without much loss and generality, but our from analysis perspective this is how you know update your variables to account for the mu being both the function of material and the response of the material to particular energy level ok.

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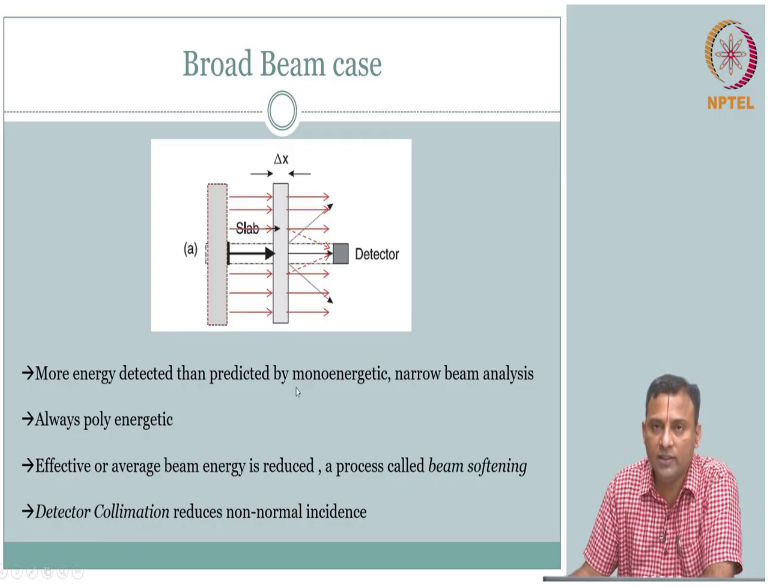

So, let us quickly move on so, much for narrow beam case. Now, we will move on to broad beam case. Again before I put the slide sketch recall or at least try to make an effort to see how this may look. When I say narrow beam I mentioned narrow in some context. What is that context? If you recall that broad beam case you should be able to quickly draw a sketch of the broad beam case. So, recall broad beam case.

Narrow beam case we said the detector size of the detector with respect to the beam width, that is what is your whether it defines narrow or not. So, in broad beam case you have a source where the photons are shot, this is much larger dimension than your detector. In narrow beam case, the source was this size the black lines that you see right detector.

So, it was about the same size as your detector. That is how we used the narrow beam case to define attenuation. So, you send it send it through a slab of delta x that remains the same here.

What comes out at the detector? The number of photons is less than the number of photons that was going in and therefore, that loss is essentially what is characterize as attain due to attenuation of the material and we came up with a model.

Look at in broad beam case, what you have? First is because this is larger than the detector size this is broad beam, but more importantly when you send it through the slab right of same delta x, what is it that you are going to detect now? Vividly, you can see here what you are going to detect is going to be still that is coming only through its line of sight. However, along with that from a signal point of view along with that you are also going to get something that is coming at an angle and hitting.

Remember the two effects photoelectric effect and Compton scattering. So, photo electric effect is the desired guy. So, I would be happy if we detect only everything along this line right. So, if something that comes through the material. So, the reduction is the number of photons that is detected if it is less than what is sent in and it is lost along this path then that is fine. I can then talk about the attenuation along this line of the material.

But, now notice in the broad beam case not only you are hitting the slab at multiple locations, but you are able to detect only with the detector width. So, signal is lost. So, you are irradiating or right you are ionizing the material here for no reason, not only that whatever you are measuring now also has Compton scattered detectors photons right.

So, it turns out that in this scenario whatever model we developed so far to characterize this interaction and attenuation does not hold good. Why? Because it turns out that we premised that what you receive in the detector is less than what is sent through and that loss is proportional to the material property right and then we came up the exponential model. It turns out here that sometimes the detector is actually capturing more photons than what entered in front of it.

So, you could have more photons here than what sent in. So, what is a question of loss right? I mean strictly use what we covered so far we would say loss is you will have detector we will have less photons than what is incident and that loss is proportional to attenuation. Here what happens is your detector could actually have same or more photons then what entered the slab in front of it.

Why? Because there are other photons which are Compton scattered that also come and hit the detector. So, whatever is lost here is not the only loss you are actually getting extra photons from the other locations. So, in this scenario if you have a detector, have more photons than what you sent in front of it, then the loss is there is no loss atleast we cannot say that that is due to the material property in front of it alone right.

So, attenuation concept and all the models that we derive does not hold good for broad beam case. Not only that when you do that you are getting if you look at the energy here, even if it is a mono energetic case right all the photons here are the of the same energy. What will be the energy at the detector right?

Think about it what will be the energy at the detector? Will it be the same energy photons or will you have a mix ok? Think about it we will just clarify that. So, more energy detected than predicted by mono energetic narrow beam analysis. Why is it more energy? Because you have the scatter scattered energies that are coming in the Compton scattered photon right that brings in some energy h mu dashed.

That one is also detected and therefore, more energy is detected than predicted by your mono energetic case. What is always poly energetic? Two things are poly the detector right is going to always detect is going to have many energies. Why? Right because the clue is here you have Compton scattered and it is all different scattering angle it can come.

So, go look back at Compton scattering you will notice the interaction is it will come, it will change path deflected at some theta scattered at some theta and goes the energy proceeds with the reduced energy h mu dashed. So; that means, if we have different Compton scattering photon each one will be at a different energy, but lower than the h mu that came in right because it is Compton scattered photon.

So, the detector is not only capturing the photon with energy that is coming through, it is also detecting lower energies because it is capturing the Compton scattered photons and that is what the detector is poly energetic. So, the whatever is you are collecting the detector, you are going to have many energies even though you have sent only mono energetic all the photons were sent with the same energy you are going to get poly energetic.

So, that means, you have many energy levels. But, then the Compton scattering that are coming in are all reduced energy right and so, if you take the average energy, the average energy is going down because you are adding new photons, the Compton scattered photons which are having lower energy and so, essentially what happens is the average energy or the effective beam energy is reduced. If something is reduced we call here we call as beam we are characterizing the beam broad beam case, narrow beam case.

So, beam we represent in terms of the photons right. So, beam softening means if you characterize the beam, describe the beam as energy packets, then beam softening implies that the energy is reduced. So, the process of beam you send h mu like there is a average energy that you sent in, the average energy you detect is less lower energy than what you sent. So, this process is called as beam softening.

If you are wondering if something rings a bell we did see something along these lines which we did not go in too much detail in the chapter for artifacts at least the introduction when we talked about artifacts right. It was not beam softening, it was actually the opposite effect beam hardening go look at the artifact that was presented in the introduction and we said it is due to beam hardening artifact.

So, now, with beam softening of course, we will talk about that further when we do the instrumentation c t and all those things, but you can already get a feel for where all it is coming from. So, this is beam softening. What is beam softening? The energy that is detected is lower right is reduced, then we call it as beam softened or beam softening or could be beam hardening if my energy is average energy shifts to greater right then you could think about it as beam hardening.

So, we will talk about that specifically when we get there, but just so, that you know right all of these are very subtle, but very physics oriented. So, now you know what is meant by beam softening and where it comes from ok. So, it is now yeah just to complete this part; that means, when we do our instrumentation we better be careful to reduce this effect right that is your Compton scattering should not come in.

So, typically we have detector collimation. So, we will try to reduce the non normal incidence ok. So, we will do two things we will try to when we do the instrumentation and when we do the imaging, we will try to make sure that we do not have a broad beam case. That is we dont eliminate the patient while we can only detect over a small area and we will try to minimize the Compton scattering using what is called as collimation we will get to that.

So, this is a take home message even though broad beam we covered essentially it is not nice, it does not amenable to the way we built our case for narrow beam. So, we will end up exploiting engineering the narrow beam case right and which is reasonable we can we have control over the source, we have control over the detector and therefore, the upper jump ok.

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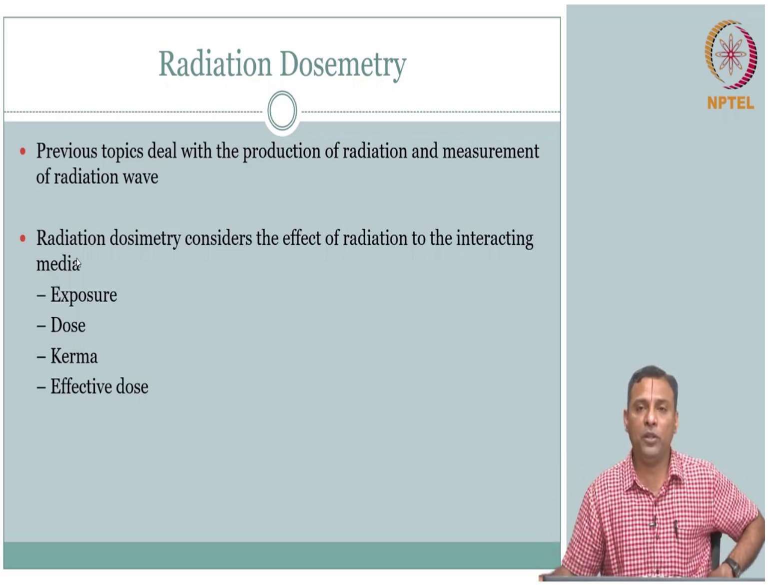

So, we will make this jump. What we talked so far about radiation, ionizing radiation, two types particulate, electromagnetic and the type of interaction each one of them has with the material and we have come a long way. After that we identified electromagnetic radiation, interaction with tissue is of importance to us in imaging systems. The particulate radiation with material was useful for your X ray tube, more specifically electrons particulate when we said we talked about only charged electrons in our context.

And when we had this electromagnetic radiation interaction with the body, we talked about two photoelectric effect and Compton scattering. But, all of this you look at the material progressively that we have developed, we have always looked at it from the imaging point of view that is your output image how close, what do you what do?

You get a output image and the intent being the output image should be as close as possible to the underlying f of x, g of x should be close to f of x comma y that is what we have positioned so far. In that context we understood the what is a signal, what could be desirable, what is a noise and so on and so forth.

But, more importantly because human beings are involved right we want to image the body human body, we want to clearly have some ways and means to also describe, understand, study, characterize, access the effect on the body. What we talked about the interaction is, effect on the signal that is coming out or the noise, but what happens to the effect on the body due to this electromagnetic radiation right, that is something that we need to study or atleast understand because there is part and parcel of the modality.

Because the image quality and patient safety goes hand in hand. So, therefore, this topic of radiation dosimetry deals with essentially understanding the what this electromagnetic radiations does to the body right that is the key in this aspect key aspect in this. But we will this is a whole field mostly this is very important if you are from perhaps medical physics background right where typically in the hospital you will have medical physicists in a cancer institute radiation therapy.

You have medical physicists, who will be able to carefully study and help the surgeons when they do the procedures or radiation therapy. They will come up with calculations and make sure that it is the safe limit ok. But, our course this is majorly tailored towards engineering and therefore, we will not really go too much into the details.

However, we will flag few key terminologies and concepts which you should know as a biomedical engineer if you have to deal with the medical imaging system, you should also know these terms and be comfortable with that. And therefore, we are in some sense we are just the not even tip of the ice berg the it is not even tip it is the pointed tip it is very very limited prick that is what we are going to do ok.

But that itself hopefully should trigger you to think about the big picture and relate this concepts to the engineering side of what we do about imaging systems. So, we will introduce terminologies. So, radiation dosimetry considers the effect of radiation with the interacting media. So, when I say that already without going into the details recall what do you know.

Somehow if you are sending the electromagnetic radiation there are two things that are happening and the desirable thing we talked about is getting absorbed right, photoelectric effect. So, getting absorbed means energy is deposited into the body right. And what are these radiations? These are ionizing radiations. What do you mean by ionizing radiations? It has enough energy to ionize hydrogen right that is our context we said anything that can ionize hydrogen is ionizing radiation.

So, in this background that we have what does it do to the body? We already know it is ionizing it is depositing energy into the body through photoelectric effect. Of course, you also have sometimes the electron can move right, the incoming energy can hit an electron; the electron can move remember all the sketch about auger electron about you know Compton scattering we did all that. So, that could also happen you could also get characteristic X ray also characteristic radiation.

So; that means, you have the body that is absorbing the energy and also it is passing through reduced energy in different directions. Some of which can also undergo photoelectric and get absorbed elsewhere right. So, the idea is this interaction what does it do to the body? It causes ionization right it gets absorbed in the atoms in.

So, the dose is deposited this energy is deposited in the body ok. So, that means, we need to talk about how all can we characterize, measure, make judgement or make basically guideline whether something is safe or not. How do we do that? So, we need several matrix to capture this the interaction is this you know that.

But how do we look at it? How do we measure it? How do we recommend what to be used? That we need to invoke few concepts and definitions. So, more specifically we will look at these four and we will try to do it in a this are all probably one slide per concept that is all it is ok. Atleast that is the level at which we are going to cover in this course, but I will try to list out what it is, but then you could relate it to the physics that we covered so far. So, what is exposure? Let us start with the exposure.

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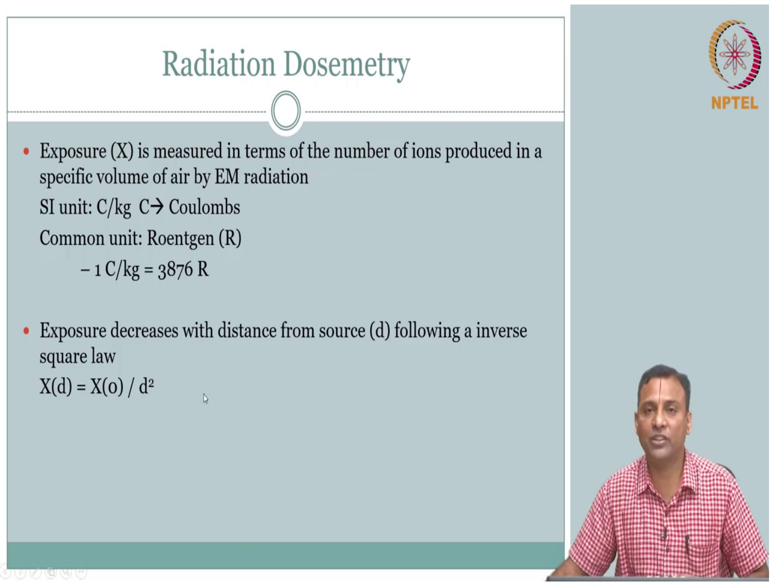

So, exposure plainly it says measured in terms of number of ions produced in a specific volume of air by electromagnetic radiation. But, just to give a brief what do we know? This radiation do ionization; that means, hydrogen is ionized, if hydrogen atom can be made to a ion right that energy is considered ionizing radiation, the effect is ionization. So, air has lot of hydrogen.

So, essentially if you pass electromagnetic radiation through air you can have ionization. So, in some ways each individual may change, each patient may change right each one is different, but X ray source I send out. So, first I need to know what is sent out that is going to hit the body. Can we control that? Can we understand that? Can we capture that?

If we can capture that then we will find out what happens when that interacts with the body because each individual is different right. So, we need to have some ways so, that we can do it in a controlled fashion to study the effect of whatever goes in with the body right. So, exposure in some sense does that. So, you can have a X ray tube that is coming, sending out photons, it is going to ionize air.

So, what happens if I make a chamber of air and pass this through? That air chamber is going to get ionized ok. So, air chamber that can get ionized means there are ions. So, if I have a voltage drop, what is going to happen? The ions is going to move across right. If it moves across you are going to have current. So, essentially what you can do is I can based on the current I can say how much ionization is taking place right.

That is why here it is mentioned exposure is measured in terms of number of ions produced ok in specific volume of air by electromagnetic radiation. So, essentially I can make a controlled volume of air right air chamber, I can send out the X ray, the ionizing radiations and measure the current. So, amount of current is proportional to the exposure, amount of ionization capability right. How much this source can ionize? If it is air at certain temperature calibrated volume, this is the ionizing potential.

So, it is exposure it is just the question of it is measuring the powerfulness, potential right. What is it that is coming out? What is kept what it is capable of you can think about in those terms ok. So, it has a SI unit as Coulombs because you have charges right per kilo gram. More commonly, it is Roentgen R right there is this conversion of 1 coulomb per kg equal to 3876 roentgen.

So, now you may wonder ok that is exposure. I am not really worried about exposures that is saying the capability in air right. What I am interested is; what happens to my body when I am exposed to this h mu. If I am exposed to this X rays right what does it happen to the body? That is what I am interested; I am interested in dose.

So, before we get to that one comment on exposure is like most other things it also obeys what we call as the inverse square law that is if I move more towards the source or away from source right. So, the distance between the source and where you are measuring right that one, where you are exposing right that has a inverse relationship.

So, X at a location d will be X at a location 0 right that at the source divided by d square; d is the separation between the source and the wherever you are measuring ok. So, exposure decreases with the distance as inverse square law. So, without knowing much right if you have a this is true even for radio activity as we will see later.

If you have some radiation going on, if you think there is radiation stay away. It is going to be very beneficial because as you step away, for every distance that you step the exposure goes down by square of that distance. So, the initial few steps that you make has a huge effect on whether you are going to be exposed or not.

So, you have to always have a safe limit. So, if you have a warning X ray source stay away, the more you stay away, you are going to gain disproportionately, you are going to be safe disproportionately ok because of the inverse square law ok.

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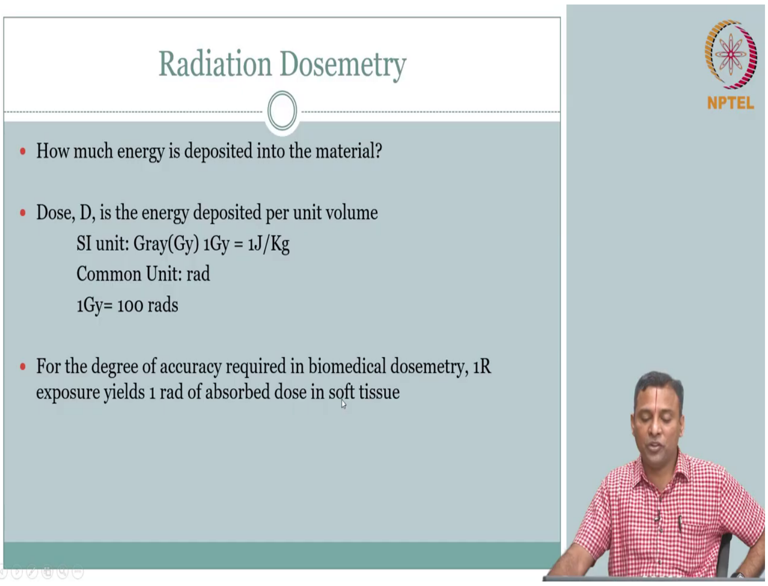

So, now the question is ok I that is all fine, exposure is fine. But, I am interested in what is going to happen to my body? What is the dose? What how much of energy is going to deposited into by body? Intuitively you know this has to depend on what? We talked about mu so much, mu energy right.

So, it depends on the material. So, I could have the same material, I could expose the same sorry I could expose a material to a exposure and it will behave differently, it will get a different dose then some other material.

So, it is material dependent as well right. So, dose denoted by capital D is the energy deposited per unit volume. So, energy is in joules right volume so we do it with kg. So, SI unit is gray most commonly we use rad rads ok. So, 1 gray is 100 rads. So, typical exposure dose that we deal with in medical system human body is about one rad your dose, your exposure we talked about two units right one is your coulombs per kg, the other is roentgen.

So, 1 roentgen will produce 1 rad that is the typical accuracy that we do that is acceptable in medical imaging systems ok for dealing with human body ok. So, that is with respect to dose. Now, we will try to improvise this further make it little more you know specific to capture see this is kind of very generic right. So, we need to customize it little more. So, for the degrees of accuracy required in biomedical dosimetry, 1 roentgen yields 1 rad of absorbed dose in soft tissue ok.

So, this is all rule of thumbs right ball park that is all. Why? Because there is a soft tissue you already saw, soft tissue you could have bone, fat, muscle you already saw the differences right mu is different in each of them. So, in some sense even though you say soft tissue it is all ball park right take it at that level.

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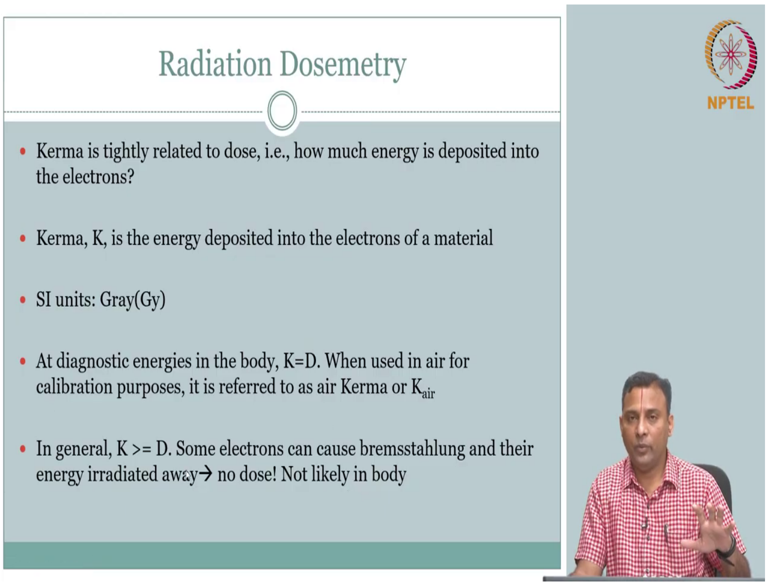

So, what did I mean by some more customization? Ok. Kerma why is it. So, what we talked about is a absorbed right, but if you think back what are the interactions that are possible. One is absorbing the other is this energy is knocking off an electron, giving the energy to that electron and the electron is now moving right.

That becomes a particulate, E is moving with energy that can go do particulate interaction that is where we left, we said even though electromagnetic radiation interaction with the tissue can generate electrons with energy and that will have particulate interaction with material which we covered earlier as what we mentioned at that time.

So; that means, the apart from the dose that is absorbed right there is this other effect that is going to be because of this particle charge electrons getting this energy and moving out. So, kerma is tightly related to dose, but here when we talk about dose here it depend it is more related to the deposited into the electron specifically. So, kerma is the energy deposited into the electrons of a material. Why is this important? I mean why is this different and also important?

Difference is now we are talking about energy deposited specifically into the electron. Why is it important? Because the electron now if it is getting all this energy and it is going now it is going to have an interaction of particulate with the material right that is going to have characteristic radiation that is potentially could have a bremsstrahlung as well right that was the interaction that we studied for particulate it could have both. So, it is slightly different from your energy absorbed.

So, it has a units again dose. So, you have gray, but for all practical purposes because in human body when we you know when we talk about biomedical application at the diagnostic energies that are involved, the effect of electron getting the energy and it going having particulate like what we did in X ray tube.

X ray tube is different I mean you know at a higher energy level that happened whereas, for typical energies that we are talking in that is going to go through the body which is your diagnostic energies your K is same as dose meaning you are not going to have much effect because of the electron going with energy and causing further harm ok.

So, how do they do that? When used in air for calibration purpose it is called as air kerma. So, the same concept when applied in air right, what we did for exposure right. So, similar things. So, if we can do it in a air, then you can get what is called as K air. So, we can relate right in general K is greater than dose clear because you can have chain effect.

But, then because some electrons can cause bremsstrahlung and energy is irradiated away. So, but all this we do not really worry about in our case right in the body ok.

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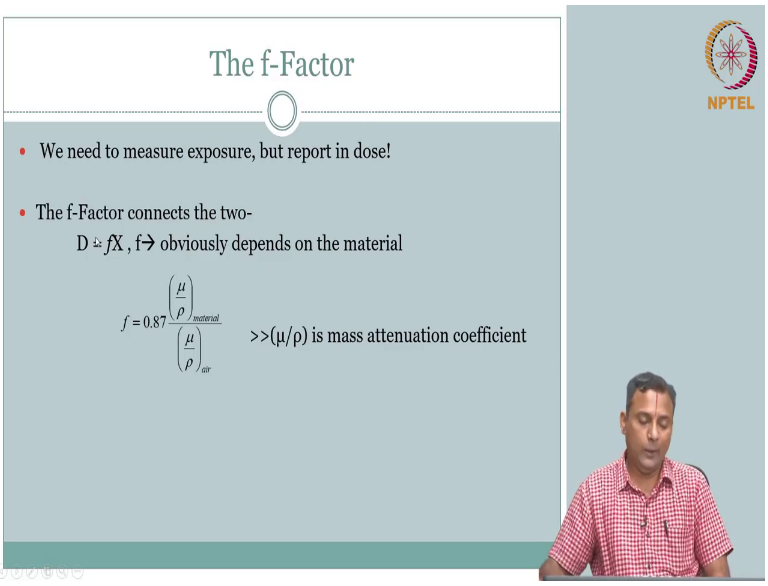

So, fine, so, we talked about exposure, we talked about dose, we talked about dose with the specification of only if it is with electron so, that was kerma. What we have not done is we have not really related the exposure to the dose. We separately defined and we also intuitively know there should be some relation right.

What is that relation going to be? Somewhere it is a material property is going to determine the dose for a given exposure that much was intuitive, but we did not strictly connect these two. These two will be connected based on what is called as f factor. So, we need to measure the exposure, but then report dose that is the thing right.

So, when we say this X ray tube this is the exposure for this setting, but then when we have to report we will have to report so much dose is given to this patient. So, you see the problem. So, I can calibrate and say this source is going, this is the exposure that you get out of this X ray tube in this setting whereas, that is not of interest, we are interested about the patient I want to know how much am I dosed.

So, you may be able to calibrate that part and get a exposure, but then I have to report what is that dose. So, that there is a connection to relate these two which is called as f factor. The f factor naturally it has to relate based on your material property exposure, dose. So, exposure you have if you expose if you does this much capability to ionize how much is deposited which is a dose it is going to be a fraction, f is going to be the fraction and that depends on the material ok.

So, f is nothing, but this number here. What is this? Mu by rho; mu is your attenuation coefficient, rho is your density of the material right and this is your air calibration. So, you can essentially use, this is a unknown material, this is calibration air. So, exposure is calibrated in air. So, I could get my dose for a unknown material.

So, what is mu is your mass attenuation coefficient ok fine. So, what is of interest now? Ok. So, there is a relationship between f I mean your exposure and dose which intuitively is related by some material property more specifically, it is the attenuation per rho. So, it is your mass attenuation coefficient that is going to determine.

So, you have several tables in the different textbooks that we are using if you look at it, there are several tables that give about exposure and dose for different materials right. We can look at it.

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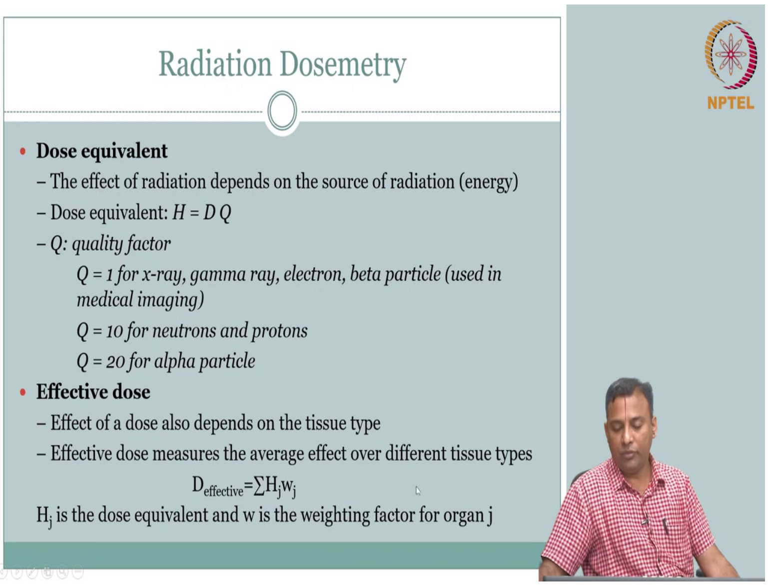

So, what we will kind of wrap up is last but one is the dose equivalent. What do we mean by dose equivalent? So, we understood dose, we understood exposure, we understood dose and we connected those two as well using f factor. But, then what is dose equivalent?

Dose equivalents is so far we have only talked about energy absorbed this dose, ionizing radiation, interaction with the material, absorption electrons that are moving right. So, dose or kerma, but we never really. So, it is all general right we could use that for anything. But, then there is some more specificity that needed because there is lot of inputs, knowledge that the effect of radiation actually depends on the source of radiation.

Meaning we are exposed to radiation right. So, there is this cosmic rays, you have so much cellphone, radio frequencies are all around. So, the we are getting radiated right, but not all of that are harmful or not all of them are equally harmful or equally safe right. Some are more detrimental, more harmful, some are ok. So, clearly there is an effect that depends on the source of the energy, source of the radiation. For the same dose, if the radiation source is some radiation source could be more harmful than the others ok.

So, we need to capture that. So, dose equivalent essentially talks about that, H is equal to D Q ok. What is D? Your dose, H is your dose equivalent. So, what is this Q? That Q is your quality factor and depends on the source of the radiation. So, Q is a quality factor and roughly Q is 1 for x ray, gamma ray, electron.

So, most of the medical imaging system that we will cover right, the radiation involved in our medical imaging system, your quality factor is one means your dose and equivalent dose; dose equivalent are same no big difference. But, they can be very different for example, you can have quality factor could be neutrons or protons or alpha particles look at this.

So, 20 types so; that means, what it is saying is your dose could be same right, but the harmfulness will be more if that source if the dose is coming from alpha particle. And how much? It is 20 types. So, dose equivalent is 20 times if alpha particle is depositing that dose.

So, origin of this source right the source that the kind of source that has a effect, I mean as a effect we are talking about detrimental biological side effects ok. So, you could have we will not go too much. But, why are people worried? Yeah because we are ionizing this there is a risk associated and it is known to have a carcinogenic meaning cancer causing effect ok. So, that is why you know these are very important to understand and study.

For diagnostic purpose, we will not make much difference between dose and dose equivalent because quality factor is 1 ok fine, dose equivalent. So, we have in systematic fashion we have come about calibration what is the exposure right. We talked about the potential to cause ionization, how much is coming in and then dose, how much of that energy is deposited and then we connected exposure and dose.

And then we said ok this much is fine, but depends on what source it is, your dose equivalent could be more but you think about it we also know it is material dependent. So, we have multiple organs, we have multiple tissues. So, for all of what we covered so far if we have to be correct, we will have to report the dose in different tissues, different organs separately right then it becomes cumbersome.

So, a patient x, y, z is going, we need to be able to talk about the dose that patient is getting exposed. We otherwise it is going to be a chart, it is going to be this is the patient. In this patient you know skull this is the thing, your heart this is the thing or even your soft tissue, this is your fat so, much is deposited. So, we will have a chart right that becomes.

So, it might be not. So, that is being really homogeneous inhomogeneous right because we know it is material dependent and material is changing throughout the body and therefore, we will have to calculate everything for each one of them. I think in being principle yes you can that is the idea right, I mean that is what is happening. But, practically I think it is easier to characterize dose that a patient is getting rather than all the different material compensated at different locations.

So, we are more interested in reporting the effective dose. What is effective dose? Depends on the tissue type right. So, effective dose is nothing, but average a collection right effective dose measures the average effect or different tissue types. So, you give some weighting.

So, H j is your dose equivalent right we did not make a big difference between dose equivalent and source, but for general purposes it is a dose equivalent, W is the weighting factor for that organ because based on the tissue type right we could do that. So, because of this effective dose concept, we could say this patient had was given so much dose during last imaging right.

We do not want to bring this patient again to do one more scan because dose will increase. So, we cannot we dont want to do the follow up every three days because we will probably give more doses. So, I mean all that is on an average based on the effective dose ok.

So, I guess this is a good point to stop completing the radiation dosimetry. Most of this radiation dosimetry like I said is a separate field where typically a medical physics physicist position will be there in a imaging centre or a hospital and they have to deal with all of these concepts day in and day out.

Because the source is changing, the patient is changing, their history is changing, the medical history of the patient is changing. So, they will have to do this customize this for patients specific, but for our purposes we will not delve too much more on the radiation dosimetry beyond what we covered in this lecture.

So, now it is time for us to move ahead having covered all the basic physics with respect to interaction and creating terminologies, capturing and having the models to capture the interaction. Now, we will start with the first imaging modality that we want to cover which is going to be your projection radiography. So, we will do that in the subsequent lecture.

Thank you.