Introduction to Biomedical Imaging Systems
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Lecture - 30
Planar_Scintigraphy_Im and IQ

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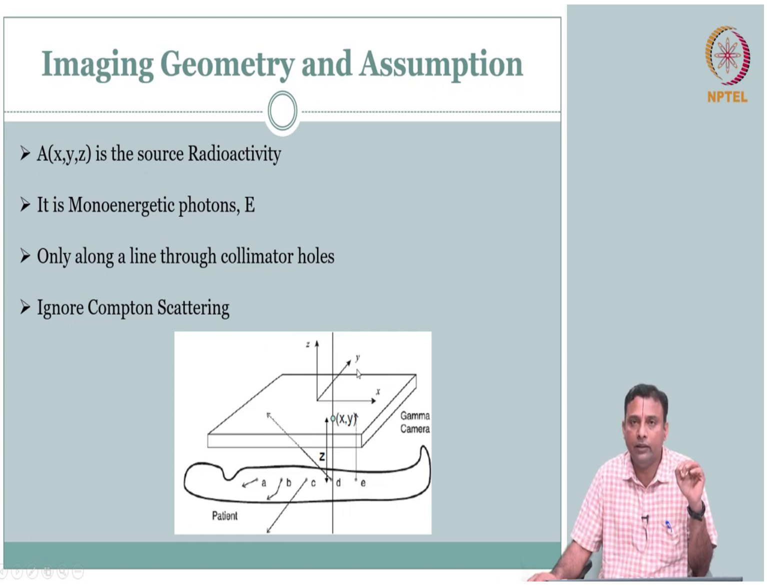

Ok. So, we have completed the Instrumentation Aspects of Planar Scintigraphy. So, we could now move on to the Imaging Equations right. So, what is the context ok here this is the geometry that we are going to deal with. As discussed so far it is probably very evident that unlike your X-ray projection radiography, the source right in X-ray projection radiography the object was there source was on one side the detector was on other side.

Here the major change in the geometry is because of your source is inside the object right in that sense. So, this is your source and this is your detector. So, we will use the same x and y for in plane and z dimensions to relate to the depth right or the source detector distance ok. So, as you would see what is the paradigm that we are looking at here see it is a probabilistic thing right. So, you take the you give the radio tracer; the radio tracer is going into the body. So, now, the source can be anywhere in the body right it is circulating.

So, you have radioactivity come out. So, after it comes out radioactivity can essentially not leave the body right it can still get absorbed inside the body that is one possibility which happens, then it may get you know. So, here it does not come out of the body or it may come out of the body like these cases, but it can actually go in some other direction where the detector is not there, ok. So, that is again a chance for that. So, if you account for all these chance even after you have the radioactivity distribution only a portion of it which actually comes on the same side of the detector has a chance to go to the detector.

Even there right there could be it could probably go in direction which is not you know hitting the detector right in this manner right. So, remember we had collimator and therefore, the collimator is looking for straight line of sight. So, even though d might go all likelihood the collimator will not take it right. So, if you write our imaging equations we will have to consider that we are going to use a collimator and therefore, only straight line paths are going to be used and in this geometry if you notice there is a chance radioactivity is distributed everywhere right.

Three dimensional here, but there is a certain portions that will come and hit the detector and we will assume that only those that are coming parallel to your z axis, parallel to your collimator right where there hole only those are going to fall on the detector and you know make its way to the image. So, what we have here is a radioactivity we will denote it by A of x comma y comma z right this is same denotion we used earlier when we started with the radioactivity.

And, another important aspect here we will consider Monoenergetic photons with energy which is not unreasonable right we talked about certain tracers and one of the desired aspect of a tracer is to give out a particular energy. So, this is not this is going to in some sense make our life easier compared to our X-ray projection where you could get spectral.

And you know very intuitive from here because of the collimator that we have talked about, we will assume that only it is along the line right. So, only along the line. So, parallel to z axis parallel to z axis is what you will get the radioactivity into the detector it will not come at any angle. So, we have arrested the Compton scattered once right because of the collimator and so, we will not worry about that.

So, now how do we write our imaging right equation given this scenario what is our imaging equation? In some sense it is very similar to what we did for projection radiography right you could think about how we came up with the first equation for projection radiography right and then we simplified that for CT used Monoenergetic equivalent and so on and so forth. So, here is very similar radioactivity comes out only through the line it come you know that comes that it is the detector.

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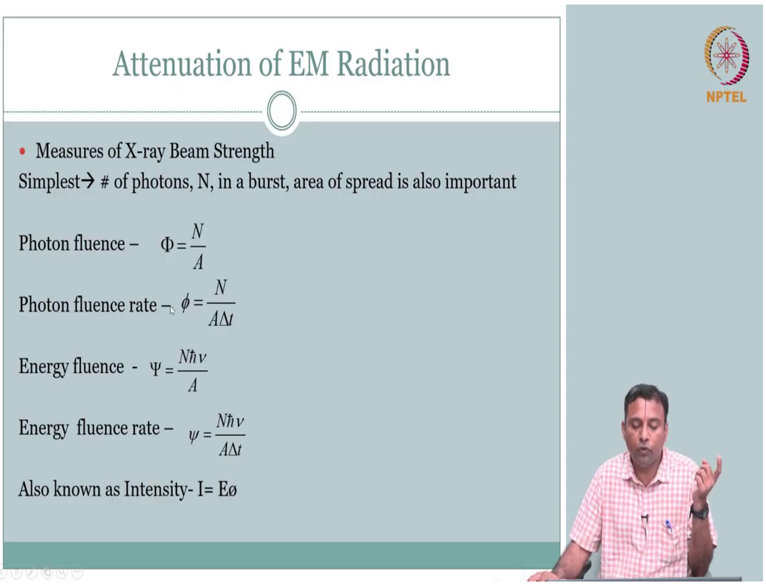

So, we will try to first start with what we know, right before we jump in one clarification in X-ray when we did we were interested in writing everything in terms of intensity whereas, here we will make switch gears we will write the equation in intensity as we know from before, but then subsequently switch over to your fluence rate photon fluence rate because here you are your interested in radioactivity ok.

So, that will be a small switch instead of I we will write the I and appreciate how it is similar to what we had done for projection radiography, but then switch over to your photon fluence right. So, this is what we will do.

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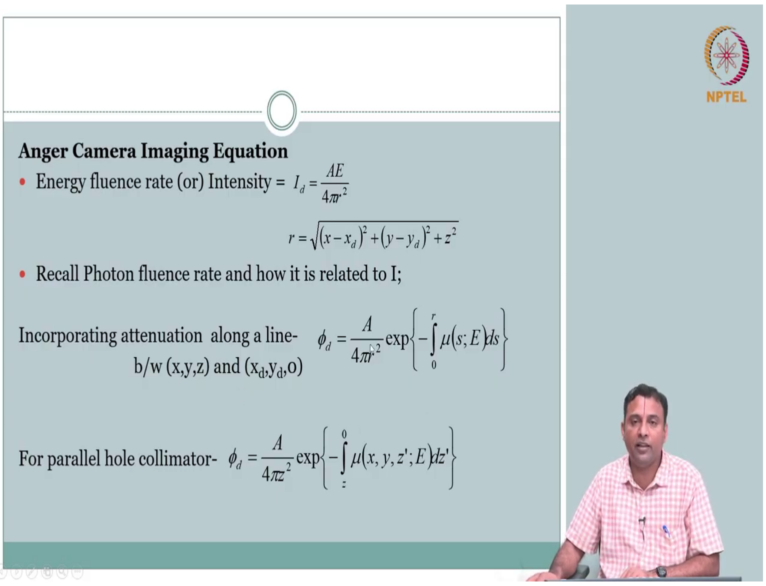

So, if you have the anger camera the equation you can write the intensity as radio activity into so number of photons right into E energy per photon. So, this would be your intensity falling on the detector where r is just the distance from x y z to your location on the detector right x comma y comma x d comma y d comma zero ok.

So, that is from the source to the detector. So, you will notice that there is this 4 pi r square. So, this is a inverse right inverse square law remember. So, nothing fancy. So, we have done this before, but again we said we will not worry about intensity we will switch to photon. So, we will replace intensity with photon.

So, we can write right we can this is not a big deal right we have energy it is ok we will start to write in terms of only A ok. So, that is fine. So, we can quickly change the equation instead of photon intensity it can be number of photons, but along the line we will also incorporate. What do we want to incorporate? Attenuation.

What do we mean by attenuation along the the source is right somewhere in the body. So, when it is trying to come out it is to cross certain part of the body right, of course, there is also medium before it; hits the detector. So, in general you can incorporate a attenuation the radioactivity is getting attenuated. So, we can also incorporate that between x y z and when it hits the detector x d at 0 ok.

So, if we do that we can write your phi d instead of I we are writing it in terms of phi d photon fluence as A by four pi x pi r square exponential of your attenuation coefficient along the line 0 to r right clear. So, this is exactly I mean very similar to what we had for yeah X-ray photon and we wrote it in intensity before ok. So, nothing surprising here, but then this looks ok right, but then we need to as we go along we will do this again and again repeatedly.

It looks very similar, but there are subtle changes that we should appreciate ok. So, even this we can kind of simplify further because we said we are going to be interested in parallel hole collimator. So, if it is coming at some angle right we are not really interested in that we will pretend that; that is not going to contribute to image, it is going to be arrested by the collimator absorbed by the collimator. And so, we could instead of having r right instead of having r we can have only z right along parallel to z right collimators are parallel to z.

So, we could write phi d as instead of r only along z you are going to have everything parallel to z right. So, your A by 4 pi z square along z is what you are going to have the attenuation ok. So, it is not going to come at some angle. So, this is your for parallel hole collimator configuration this is what is falling on the detector you had a source and the source is attenuated along the line and this is the radioactivity that falls on the detector after going through the collimator, ok.

After going through the collimator what is there crystal ok. So, we will come to that. So, this is what at least you have led in ok into the camera ok. So, is this good or is there some simplification we can think about? Well before simplifying we will have to see whether it is generalized right. So, now, look at what is this A? A is a radio activity that is fine, but A is what? A can be anywhere right, A is a function of x comma y and z of the body it can be front of the body, back of the body it can be from the head, it can be from the toe. So, it is distributed. So, A itself is a three dimensional right distribution.

So, we will have to first upgrade the equation and then see how all we can simplify ok.

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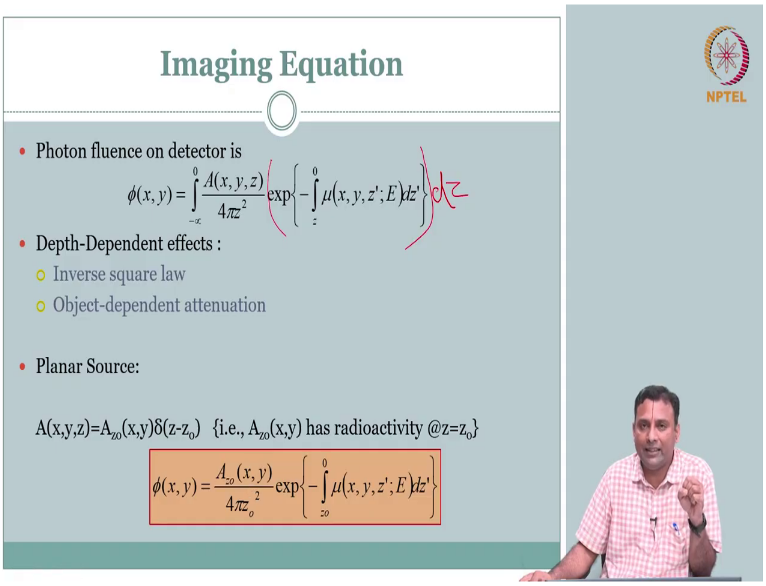

So, photon fluence on the detector right that is what we are talking about is phi of x comma y. So, what we have now we have made it little more general A is x comma y comma z of course, it is rest of it is fine right rest of it is fine of course, you have made this along z from before right only along the line of parallel to z only parallel collimator right. So, parallel whole collimator. So, this is fine.

So, we have now basically said whatever is falling on the detector plate x comma y detector plane right is whatever happens from the source along the z you have the integration of course, there should be a dz here ok there should be a dz because this is going over minus infinity to 0 ok A x y. So, there should be a dz i will update the slide, but ok. So, there should be a dz ok. So, the idea is yeah you have along the line right. So, you have a thickness. So, A x y z is the source distribution.

Well it looks very similar to your projection radiography nothing fancy, but only difference is of course, this E can go out this so actually in projection radiography it was little more complicated we had another integral for the energy levels right of course, when we started we conveniently said source is a X-ray tube. So, I s was in whereas, here that integration is not simplified. So, we get something simplified, but certain other things are not simplified.

So, you notice two effects here in Depth-Dependent which are depth dependent right one is your z here appearing. So, therefore, your source when it falls on the detector we have a depth dependent effect which is kind of you know we are familiar with this term, but what is important that we did not explicitly see before is this guy this is depth dependent as well naturally right. So, whether the intensity the radioactivity is in the front of the body or back of the body right, whether it is close to the detector or far away from the detector is going to have an effect because all of this is going through the same attenuation as well right.

So, you look at it the z appears both here which is your depth dependent effect and here right. So, you have object dependent attenuation right. So, this is basically what is this depth saying you have some activity in the front or back means it is going to travel your mu right your mu. So, depending on whether there is more material in front or back the path along the path that is going to have an effect as well ok.

So, this depth dependent effect this is a straight forward one which we knew from before inverse square law, but you have object dependent attenuation right object dependent attenuation mu and therefore, whether the source is more inside the body or more close to the path that the radioactivity right the photons should travel right along the mu is a function of right the depth dependent or object dependent attenuation ok. So, there is object dependent attenuation. These two contribute for depth dependent effects.

So, in other words you could have the same radioactivity from the same z right, but at different locations in one location you have more tissue to travel more mu, in other location you have less mu. So, what is hitting the detector will be different even though the starting out radioactivity is was same ok. So, it is dependent on that. So, one thing we can try to reduce simplify ok. So, this is good. So, why do not we consider a Planar source instead of having this 3-D source can I have a Planar source.

In some sense why worry about this z right, why cannot I collapse that to the plane of where the radioactivity is. So, we can collapse that and have only a plane therefore, the front or back I at least to that extent I can simplify. How do we do that? Well, same delta function right I have a volume I have to take a plane. So, essentially you can you are picking a z plane right. So, you can write your 3 dimensional A of x comma y comma z you have some at z naught. So, say at the centre of that you take A z naught you have a plane now.

A z naught because z naught is your delta function. So, from z you have taken a location z naught. So, at radio activity A z naught is radioactivity at z equal to z naught. So, you are taking a plane. So, now, your 3-D source radioactivity source is made into a Planar source at location z equal to z naught ok to some extent this has this seems to simplify because at least one integral I can get reduced right. So, I can reduce that at least.

So, now I have my phi of x comma y as A z naught. So, this z is gone right. So, that is this integral that is gone. So, you get this equation. So, this is reasonable couple of things that we need to appreciate is now it looks very similar to your projection radiography, but for one complication which is so, this is straightforward right this is along the path whatever attenuation is there inverse z.

Before we used to worry about we could integrate this into a I s and then we said that as I naught in our equations here we have your source is still x comma y it is Planar it is not one point remember in X-ray we had similar equations, but we had a point source and then we had a extended source the effect we incorporated, but for all practical purposes we started with a point source whereas, here the source is a Planar source ok.

So, that is one thing and you also notice that the I mean it is a tricky business and even though it looks ok we can comprehend this it looks little tricky in practice because even if i have a Planar source right even if I have a planar source. So, the radioactivity is distributed uniformly in a plane.

For example I have the detector right your planar source could be there, but then your attenuation along the path could be slightly different ok. So, all this will play a subtle role in explaining or interpreting the image, ok. So, that is for Planar Source Imaging Equation. So, this is a good point. So, what do we what do we need to do in projection radiography we had imaging equation and then we ended up this is the imaging equation and then we studied the image quality.

And in CT when we did reconstruction we started with this and then we talked about customized it for the instrumentation of CT and then we did the reconstruction. So, similarly here we have the parent equation ok when we go to t which is ESPECT or PET corresponding instrumentation we will start with the imaging equation and try to go back and estimate ok.

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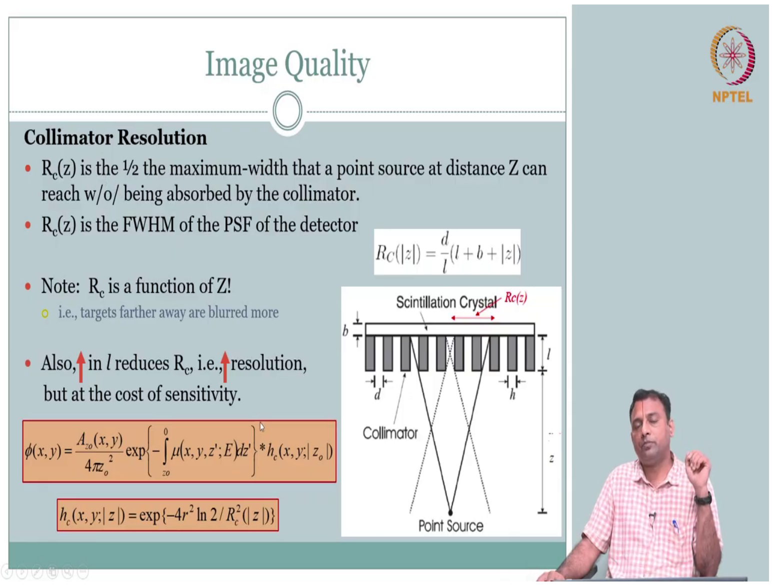

So, we will now talk about Image Quality in Scintigraphy similar what are the parameters we are going to study image qualities, resolution, noise signal to noise ratio, contrast to noise ratio right similar things. But, what is going to be different here well the parent definition is going to be similar, but the instrumentation the physics we saw to an extent we know we will draw similarity with what we have covered in projection radiography. But then, what are the unique aspects here?

Well, the unique aspect in some sense is it is the radioactivity that is counted and you have a scintillation screen and photo multiplier tube unlike projection radiography where we had a intensifying screen and the image was formed on the X-ray film.

So, there is lot of similarity, but then there is also some differences that make this you know the equation slightly different. So, first we will talk with when we talk about resolution when we talk about image quality in that we want to talk about resolution, collimator resolution is one thing because we have this collimator for what. So, that you can avoid Compton scattering right.

Avoid Compton scattering that was the idea. So, the idea is if you have a point radios activity right we talked about parallel hole configuration of the collimator. So, when you have a point radioactivity when it falls on the detector right it is going to be spread out, ok it is going to be spread out. So, the idea is we could define resolution as a point spread function for this geometry, ok. So, we what we have is we have the crystal right in front of that you have the collimator; the collimator has its configuration right a length, a height. So, you have a point source at some distance z.

So, if we call this right you call this. So, you have a point if you call this Rc or z a resolution collimator of z. So, two times this is the full width right. What is the definition of resolution we have been using? Full width at half maximum ok. So, if we do the geometry right and solve full width at half maximum we will get collimator resolution to be d by l in terms of the parameters that you see here d by l of l plus b plus z. What is striking here? So, Rc of z is nothing, but your full width at half maximum ok half the maximum width at point source at distance z right without being absorbed by the collimator. So, it can go here right it can go through ok.

So, this is your full width at half maximum of the point spread function of the detector absorbed right, but what is important here you notice this Rc or resolution is a function of z. What does that tell you? That means, whether I have the object close to the detector or far away from the detector right that is going to have an influence on the resolution. So, system resolution is not really system resolution right the collimator system resolution it is not like that.

The collimator resolution, what we call is dependent on where you are going to present the object, ok. So, that is a important message. So, if your z is more Rc is more; that means, the spread is more; that means, it is poor resolution right, if z is less the spread is less better resolution ok. So, that is a key aspect in collimator resolution. So, how else can you do better

I can kind of increase this l if I increase this l right I can reduce Rc ok, but what is challenge if you increase l I am going to be more right I am going to be more taller.

So, I will be very specific. So, sensitivity will get affected. So, we will talk about that little bit later. So, the point to note is Rc is a function of z. So, targets further away are blurred more, ok. So, this is a key point otherwise it is fine also you notice l increases Rc reduces right l increases Rc reduces; that means, l increases means your resolution is becoming better, but what is your downside sensitivity. Why? Because if it is becoming taller right you are going to reduce the number of photons that can come through remember our very similar to our grid ratio that we talked about I mean the variables the same b, h and all are used, but go look at that the you know that was in a different context right.

So, here if you notice your resolution is you can design your collimator, but with a trade off ok, but for a given collimator you can sort of play with the resolution and sensitivity by arranging the object or placing the detector, move the detector close or far from the object ok. So, how do we incorporate that how do we incorporate this knowledge ok all this is fine we understand your linear systems theory we did ok.

You had the imaging equation now you convolve that with the point spread function of your collimator ok. So, this is h c is your system response or whatever right of the collimator c is collimator and it is x comma y. So, here usually it is a Gaussian which is what is assumed ok. So, this is a reasonable model a Gaussian model is typically used and you can incorporate its effect. So, the imaging equation is now incorporating the blurring due to your collimator resolution ok.

So, is that all is there any other resolution that we are worried about because we are interested in the image, the collimator after collimator what is there you have a scintillation crystal even in image intensifying screen we notice that the there was a effect of thickness right. So, here, that means, that should also have a part ok.

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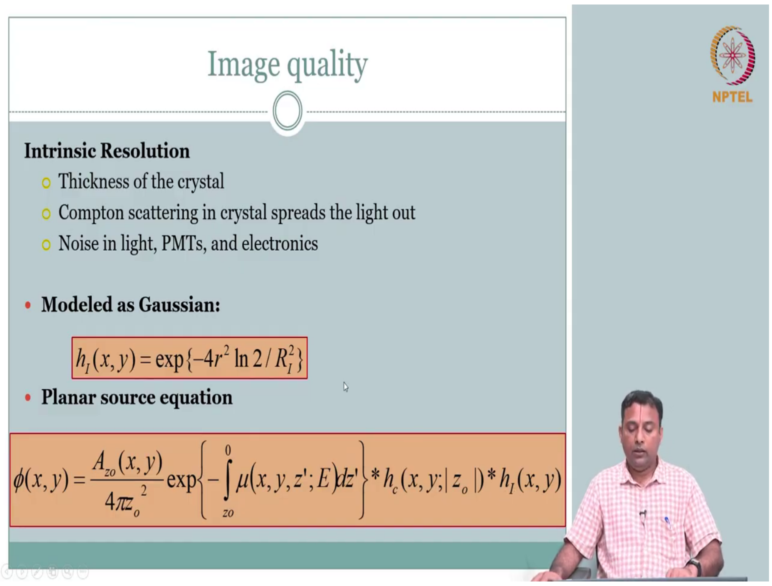

So, we call that as a Intrinsic Resolution. In fact, subtle point intrinsic resolution when we say right what is coming to our mind is ok we know this is all parameters no doubt about it. So, thickness of the crystal. What do you know about that?

Thickness we did not allow the Compton scatter to enter from the object. So, only straight line came through collimator, but after it comes through collimator right it may have Compton scattering in the crystal and therefore, some will probably go on further into the photo multiplier tube and that will get detected and therefore, you will still have Compton scattering effect on the output of the photo multiplier tube right which is what is going into your imaging equation image localization right.

So, that could be a problem. So, thickness of the crystal has a similar effect, but the Compton scattering right that spreads the light out ok. So, you have Compton scattering from the crystal point of view. So, it goes into the crystal interaction there some amount is gone. So, you could also have noise right. So, noise all that. So, what you are going to get hit right on the photo multiplier tube output signal is from the photo multiplier tube output that is located say, if it is a frame you put the pixel x comma y comma z remember.

So, intrinsic resolution even though you kind of know that these are the factors that have to be taken into effect the intrinsic resolution actually deal I mean kind of comes along when you do this x comma y right. We talked about localization, we have photo multiplier tube, we calculated the z pulse and then we did the centre of mass if you go look back to say where it came from that calculation of your x i comma y i right that can get corrupted because of all this there could be uncertainties in that because of all this and that right. So, therefore, that resolution to the precision with which you can localize.

That is your intrinsic resolution. So, it is essentially your x comma x i comma y i remember we did what we called as localization x comma y that is where you have the effect of Intrinsic Resolution ok all this contribute to that ok. So, in some sense this is slightly different from your projection radiography because in projection radiography the Intrinsic Resolution or equivalent of this if you really look at it the thickness of the intensifying screen had a role in spoiling the optical film that is it, we could not recover from that ok it was directly the point spread of the intensifying screen that directly had an effect.

Whereas here, this point right the point spread similar to there that is not directly recorded the point spread goes and hits probably multiple photo multiplier tube. So, you get the raw signal out and then you use all this signal to calculate the x comma y. So, you have some sense that you can come up with some techniques to reduce that. So, the resolution could be better than what would be a regular point spread alone in your projection radiography right.

But, so, that is the difference, but it is similar in that sense that the same effect of thickness is going to have. So, here also we will model it as a Gaussian. So, intrinsic will also be modeled as a Gaussian ok. So, these are all things that you can calibrate right for the instrumentation. So, you could do that. So, we will now update a planar source equation with all the terms A z naught by 4 pi this term exponential and the two blurring, ok. What else from a resolution point of view that is done, but we still need to talk about something called as sensitivity.

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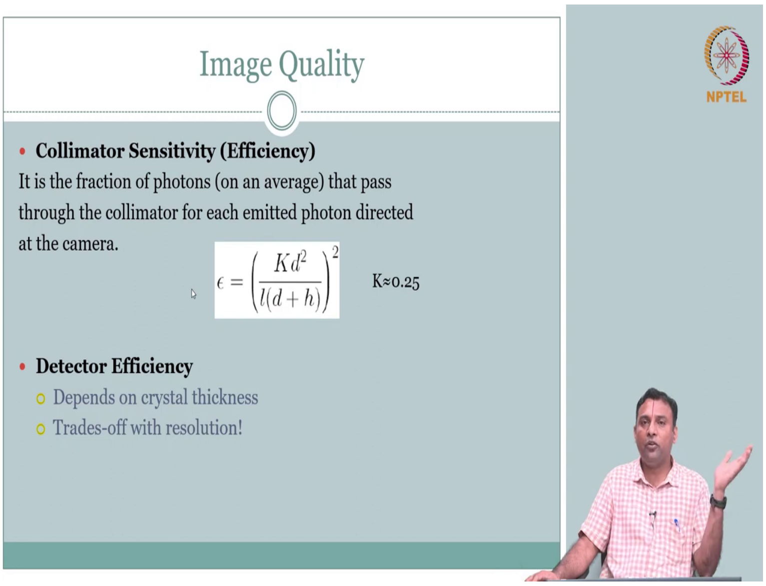

Because we kind of even mentioned that what is sensitivity it is a fraction of photons on an average that pass through the collimator right. So, the configuration of our collimator is if I have length right we talked about more length of collimator increase the l we could reduce the r or improve the resolution that is what we notice that time we said no you compromise on the sensitivity or the efficiency of (Refer Time: 33:53). So, you notice that is because if you do this right sensitivity is what fraction of photons that pass through the collimator for each emitted photon directed at the camera.

So, if you increase the l your resolution is improved, but then there is a good chance that it is going to be very specific, it is not going to let anything come at certain because it will hit the lead if it is tall right there are fewer acceptance angle. Therefore, the number of photons that are going to come through and hit the detector after the collimator is going to reduce ok. So, your detector efficiency collimator sensitivity or efficiency is roughly worked out like this where K is approximately 0.25 ok.

So, you know there is lot of. So, this has to do with your material property they try to increase the thickness remember same idea material property for a given energy thickness all of this has to be controlled, ok. So, in some sense when you have a radioactivity when you do the radioactive tracer when you engineer that radioactive tracer you have a energy band and then you engineer the detector you right everything on the detector side anger camera side, you make everything specific or as much close to the best case scenario for that particular energy right.

So, in that sense you know it is not like one detector fits all kind of thing. Each imaging study each patient right at least physiology that you are going after all that requires a proper choice of what detector you are going to use if you are going to use a gamma high energy gamma for a particular this thing study then you need to change your you know scintillation crystal. So, your camera detector side has to be changed in tune with what you are going to do ok.

So, detector efficiency in some sense is going to be dependent on all the factors that we have talked about. So, there is no formulation per se, but you understand all this is you know when in a centre they do lot of studies they may have all these calibration values. So, that they can kind of use an appropriate setting to do the imaging. So, it depends on the study right what aspect what. So, that radio tracer and the settings that they want for the radio tracer all this they will have to handle ok.

And then you get the so, you once you get the x comma y z we talked about what image is shown right ok. So, much for image quality with respect to resolution and detector efficiency, of course, we need to talk about noise. If we talk about noise we talk about signal to noise ratio, when we talk about signal to noise ratio we need to talk about more importantly the contrast, but here as you would notice nothing much has changed right you get N photons only thing is it is in the gamma energy range.

So, the photons arriving at the detector you have the same Poisson's ratio. So, in some sense the signal to noise ratio right in one detector if you will is going to be what mean divided by standard deviation; mean is going to be Poisson ratio, standard deviation therefore, is going to be square root of that mean and therefore, we are going to have and these are all number of photons right average number of photons that are coming.

Only the energy is different otherwise this is the same thing that we did for projection radiography as well right.

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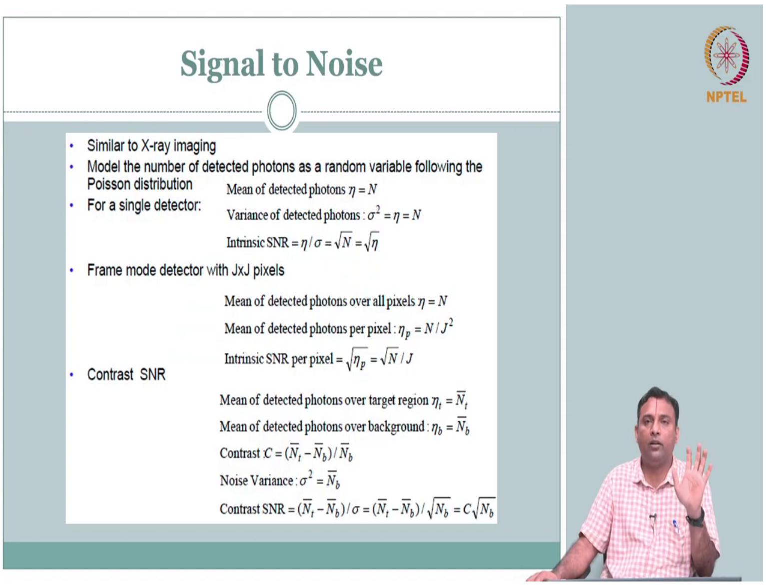

So, much is fine, but there as subtle difference. So, I will just plot I mean show that in one. So, it is very similar to your X-ray imaging. So, you can get your because of your Poisson distribution that we saw intrinsic SNR is square root of N, no big difference. What is the context here though is here you have a detector when we talked about detector especially if we talk about that frames like static mode right we want to talk frame detector mode what happens you we talked about having pixels right some J cross J pixels ok.

So, now if it is having J cross J pixel if you look at per pixel right. So, mean of the detected photons. So, here that is the difference right. So, here when the photon comes right even if it is spread the photo multiplier tube it gets picked and we are calculating we are adding all that. So, we are calculating the z. So, what comes here comes out maybe it is spread out and therefore, we are trying to localize it by calculating z pulse and having the threshold and doing all that.

So, in some sense that is fine, but per pixel what happens? So, mean detected photons if that is N you are going to have that over J cross J right. So, it is going to be mean detected photon per pixel is going to be N by J square and therefore, your intrinsic SNR is going to be root N by J. So, this is the slight contextual difference to your SNR per pixel in your scintigraphy.

But, why is this important to highlight? What this says is you might intuitively think if I have you know 256 cross 256, it will be better I mean or 512 cross 512 right I might be better if I am given a choice between 256 cross 256 and 512 cross 512 or 128 cross 128 you would think ok the more the pixels right I would go for that right you have better resolution you would think. So, you want to go for that.

But, what is the downside your intrinsic signal to noise ratio goes down. So, there is no one solution I mean naturally right your detector size goes down if you increase the number of pixels. So, your localization is better, but then your number of photons that is reaching is less and therefore, your intrinsic signal to noise ratio goes down. So, it is a trade off ok.

So, there nothing is like I say in imaging cut that is one commonality between amongst all the different modalities there is no easy way out, there is no easy solution, there is always going to be this compromise or trade off amongst the various parameters of image quality ok with the various physics some are physics limited some are instrumentation, you know complexity, but there is a inherent trade off that is what is important you try to understand, ok.

So, that is otherwise the rest of it is very similar. So, you can have a contrast signal to noise ratio remember we talked about this and pretty much the same derivation you get C of square root of N b. So, that is now big difference in this part. So, this kind of completes the scintigraphy that we wanted to cover I know it was a quick coverage, but this is at the level of introduction to the subject right there are intricate details that you may want to jump in and read and study especially if you are from say material science kind of background.

You may have lot more to do with development of crystals and the converting the efficiency and so on and so forth ok. But, otherwise I think this is giving a good start our next agenda is ok it is equivalent to our planar radiography right analogous to your in X-ray we did projection radiography here we are done planar scintigraphy right, there we did computed tomography. So, here we should also get some tomography, right, we have collapsed the object A x y z we have collapsed, but in reality we would like to know where the radioactivity is along the depth right.

So, if we take a particular cross section we would like to know where the radio activity is along that z, right now in planar scintigraphy that is lost. All we know is maybe that radioactivity is coming from the head or chest or abdomen you really do not know whether it is from front of the abdomen or back of the abdomen. You do not know which organ there is accumulation ok. So, we need to naturally go towards tomography which we will do in the subsequent lecture.

Thank you.