Introduction to Biomedical Imaging Systems
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Lecture - 19
Film Screen_Optical Density

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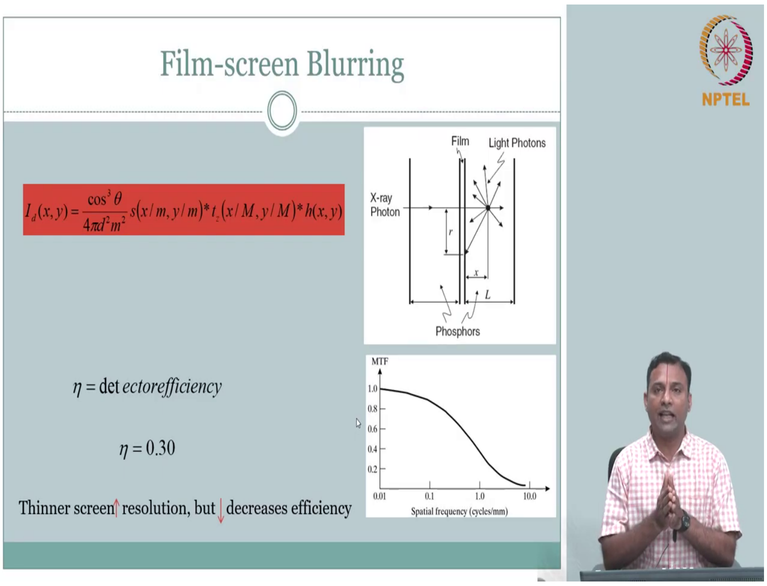

After film screen right, is that the end of the story? We want to see how the image formation happens, right. So, we talked of the instrumentation, we came until what we call the film screen blurring. Now, is there anything else that we need to consider or is this fine, are we good to go to talk about the image quality, do we have the image yet? It may seem that we are almost there, but we still have not talked about the last bit of the instrumentation and that has to do with this film.

See we talked about film screen, the intensifying screen, so that you can convert the X rays to light photons and that light photons spoils the film. And then what does the physician use? He takes this film, develops it and then he looks at you know in front of a light box right; you would have seen white light will be there and he will hold this developed film in front of it and then interpret whether you have a you know simple case that you would have encountered is, whether there is a fracture or not, right.

So, we are almost there, but we still have to talk about the film; because in the end the doctor is not interpreting what is there in the film screen right, I mean it is still not this one. Somewhere this information of light photon is getting onto the film that, you can think of it as the last subsystem right; I mean the last subsystem before the physician looks at it and makes a interpretation, ok. So, that means, we need to talk about the film characteristics.

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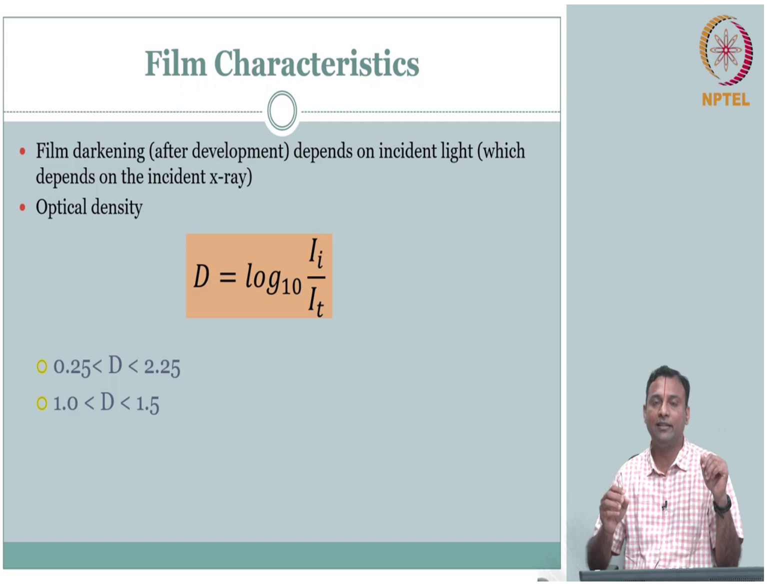

So, just you know what, what is the process, right? What is the process, what do you think a film characteristics that we need to worry about? First and foremost is because we have done even in the previous module right, when we talked about film screen; we were always interested in some resolution that is lost, the point spread functions.

So, we have been consciously using the point spread function and the linearity to build our case right, update our imaging equations. But now the question is ok, do we have to worry about when, what do we mean by film characteristics?

One of the characteristics is you have the film screen; the film screen right, the intensifying screen, creates light photon and the light photon goes and hits. So, we just concluded how the thickness has a effect on the resolution.

So, we modeled it as a point spread function of the screen. So, in principle, if we are really you know really wanting the details; we could say the film right, what point forms on the film, right. If one photon, one point falls on the film, when you develop it, the process of developing and then you take it out and look at it in; the develop how much the point spread does happening that could be used. But it turns out it turns out that is not a limiting factor; as we saw when we have multiple subsystems each with its own resolution, it is the poorest guy that is determinant, right.

So, here it turns out that the film characteristic for resolution, it has a much superior capability to localize than your film screen right, the intensifying screen that we saw. And therefore, in relation to that, this is not going to be a limitation and therefore, usually your film characteristic, the resolution aspect of it is not much worried about our analyst.

But in principle you could if you have for whatever reason you, you have ah you know requirement; then you could just model it as a point spread function and convolve with our imaging equation that we have already, no problem.

But what is more important it turns out is, look at the process; this is the image like, the film is going to be developed and the doctor is going to make a diagnosis based on that. So, the image quality, the image interpretation right; the f of x comma y that is input the input unknown, there is a inherent contrast right, how does that get captured in this image that the doctor is viewing. So, what is this image, what is the units, what do you see?

When you see black and white and grey, what is that? Is that the X ray photons? Because your unknown distribution is your attenuation coefficient for X ray photons, right. So, is that what it is or if not what is the characteristics that we need to worry about?

So, it turns out we are not interested in resolution per se of the film, because that is superior; but how does it transform? So, look at the process you have X ray photons go into the body right, X ray photons interact with the body; it comes out through the other side through transmission and then it falls on the detector.

So, you have a line of X ray photon, come along a line, pass through the material, come hit the detector at one location, right. So, now, when it hits the detector; we have we are going to talk about this intensifying screen, right. So, it gets into that. So, the X ray photon gets converted.

So, that means it has to interact with the material, converts to light photon. Now, this light photon hits the film right, the film that you have. So, what is the film doing? On one side you have the light photon right, the X ray getting converted to light photons and the light photons darken right, darken the film. And the outside you develop the, after that you take the film, you develop and the outside is the film that the doctor is taking, keeping it under keeping under a white light and making the interpretation, right.

So, that means we need to be very careful of. So, the when we characterize this film, we should characterize its ability to transform the input to the output; because the input has all the physics that we talked about, the inherent contrast of the f of x comma y is captured in the input side on what falls on the detector.

But what comes out of the detector that is displayed to the doctor right; that we need to this transformation is happening in the film. So, we need to talk about understand the characteristics of this film in terms of how it is able to transform the input to the output.

So, the idea is the film darkening after development depends on the incident light, right. So, incident light, so just contextualize; say if you had along the path you had a bone and another soft tissue, you know when you go for a bone fracture, I am sure you would have had a chance to look at least somebody's X ray with the bone fracture. You will see the bone is not going to be dark, the bone is going to be white right, at least on the brighter side.

So, what is happening? We know bone is more attenuating. So, when the X ray photons go through the bone; if there is bone along the path, X ray photons will get attenuated. So, less number of photons will come in its shadow right; so that means that X ray photon is less, that is going to spoil only less. So, that means it is going to when I say spoil, this X ray photon gets converted to light photon and that light photon darkens the film.

So, this darkening is proportional to the number of photons that are coming in; this number of photons that are coming in X ray range, I mean coming in light photons that are darkening this is proportional to the X ray photon, number of X ray photons that are coming, which is proportional to or which is determined by your material property that was attenuating it along the path.

So, in some sense the film darkening is proportional right, it depends on the incident light in the screen; that incident light is dependent on the incident X ray right, that is where we talked about this conversion efficiency of your phosphor active material all those things. So, this is the idea. So, the input side is the physics, the X ray photon that is coming through the body which captures the material property; the output is the a film darkening.

So, this film darkening you know is interpreted the doctor takes the developed film right, the darkened film, keeps it in front of a white box; if you I mean we you have been you probably saw people taking light they have and then look at it.

But usually formally what is done is, you have a light box which will be homogeneously white; they will keep the x ray film right in front of that clip it and then you can see the x ray, read the x ray ok, x ray image, which will appear grey shades of grey. So, essentially what we are interested in is, the x ray that is interpreted the output image is nothing but is optical density; density will be more or less depending on the amount of darkening, which will be dependent on the amount of incident light, which depends on the incident x ray.

So, if you have more attenuation in the material, you will have less photons incident x ray; that when it gets converted, you will have less darkening and that if you look at the opt, so optical density right, so you will have more, it will appear more white. So, formally it is defined as D is equal to logarithmic base 10 of I i by I t.

What is this I i and I t, ok? I is irradiance. So, what are we talking about, we are talking about the x ray film which is developed right, this is darkened. So, they keep it in front of the white box. So, light goes through, the film is there and the human observer is on the other side.

So, back of the film there is white light, which is trying to illuminate all the region with the same white; whereas there is a screen that is a film that is blocking and then the reader or the radiologist is on the other side interpreting it. So, the light has to go through the x ray film, this x ray film is nothing but developed which has a darkened, the amount of darkening depends on its exposure, right. So, you have irradiance on the input side, what comes on the output, so what is transmitted.

So, irradiance on the input side, irradiance on the transmit; what is coming in, what is coming out. So, that means if you have transparency transmittivity. So, this I i by I t right is called opacity; because I t by I i is your transmittivity, I mean how much of is this transmitted.

So, if I have light coming this side white light right on the input side; if this is a dark right, the outside you will have less signal right, it will appear grey, but it will be dark black grey. Whereas, if I have transparent part, the light will come here, everything will come out, right. So, you will have your transmittivity. So, I t by I i is your transmittivity.

So, the inverse of that the reverse of that I i by I t is your opacity, how much is blocked, how much is transmitted, how much is block whichever way you can write it. So, definition of optical density is, it is a log natural 10 of your opacity, clear. So, now, you see the point.

So, we are actually ending up interpreting the optical density; but that optical density is related to the distribution of the x ray that is coming in, which is distributed through or correlated with that distribution of your attenuation coefficient, clear.

So, I hope you are able to see through the instrumentation, the physics all of them are culminating here. So, the image that you are seeing, the each pixel that you are seeing; whether it is a black colour or a grey colour or a white colour, I think you should be able to connect it to the underlying signal chain that we just saw, both from physics, instrumentation, right.

So, much for optical density, this is what we do. So, naturally what is the range? Ideally you want to have a good range; you want to see the darkest portion as well as the brightest portion in the same thing.

So, you can distinguish, the whole idea for us is contrast; whether there is a fracture or not, because the there is bone is continuously white, it is one piece. If there is a small crack, then there is probably different material air or a you know liquid. And so, the darkening will be different at that location; so can we tease out this white from dark or grey.

So, it is always a contrast that we are looking for, right. So, in this paradigm if you look at it, typically you get a range 0.25 to 2.25; this is the range of distribution that you can get in your optical density.

However, in the paradigm that we discussed, the doctor is looking. So, it is your then stuck up with your visual, human visual perception; how much can I, how much of the shades of grey can I actually distinguish, how much of shades that I am comfortable, that my eyes are normal human physiology eye physiology, right. So, it turns out 1 to 1.5 is very comfortable range, ok. So, this is your optical density range that is comfortable for human observer or the desired range where you like to have, ok.

So, much for optical density and the interpretation of that; but to think about it is this sufficient, I mean are we good to go, right. Is there anything else that is missing? Probably what we did not cover yet is fine; we know the output now, we know how to interpret the output. But then you said on the input side you have the x ray photons or the exposure; so this this film right the characteristic the film that we are talking about, in some sense it is exposed on one side, that exposure leads to darkening.

So, the output is after you develop it, the you can characterize the output or measure the optical density. But can we now have some relation, because we have to talk about this film; we know how to read the film, but then what is a good, I have a film A from manufacturer A, I have a film B from manufacturer B or same film I have different specs from the same manufacturer.

How do I, how do I assess the performance of this film? Do I have a way to measure its performance right or what is its influence on the output image when this transformation? And therefore, that will allow us to use that as a metric to use appropriate film for the purpose.

So, what do we need? We need some handle on to connect the exposure and the output image optical density; on the input side is the exposure, the output side is the optical density. So, we will have to characterize this film ability to map one to the other, right. So, we need to talk about how does the film perform in the in this, how much of exposure yields how much of optical density right, so that conversion that is a factor that we need to study.

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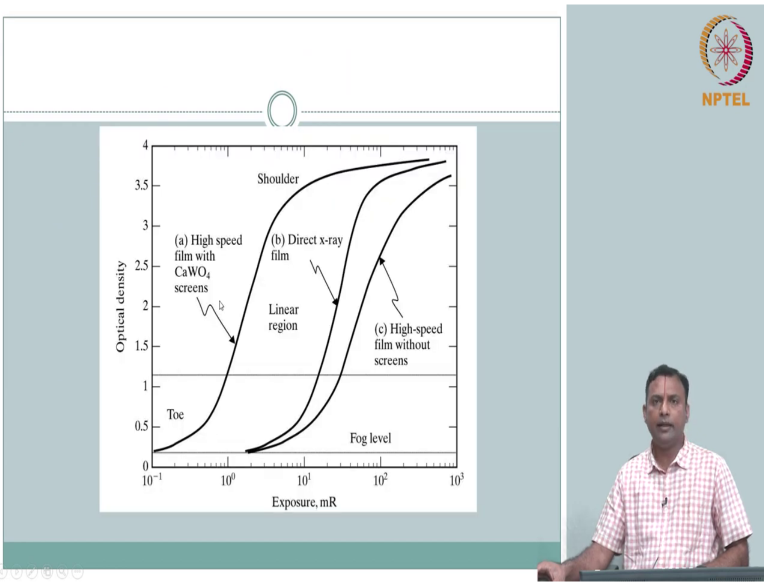

So, typically that is done using what is called as H and D curve; what you see here is an example of a H and D curve. In fact, qualitatively I think you might know some of this right, I mean in a different context.

Say if you take a photography, I know we are all into digital photography you just take it; but at least those amateur photographers right, at least when we a decade ago or couple of decades ago, we used to have this craze ok, can I go do SLR, can I what are the functions parameters that I can control, right. A difference between a amateur photographer and we taking a mobile is, they go and try to optimize how much of exposure should I give; can I go slow, can I capture the contrast.

So, they try to understand that in the context of the film, right. So, some will do very good with the Kodak film, some will take their photo to capture the best for Konica, right.

So, they have different vendors. So, each film has a different characteristic of how much exposure to how much output contrast it can capture. So, similar thing here also, inside is one input is one side is exposure, the output is optical density. So, similar concept is applicable here also and therefore, you have this H and D curve, which can be analyzed to study the characteristics of this film. So, your exposure on one side, optical density on other side; what you see are you can look at it, these are called characteristic S curve, why because it looks like S, ok.

Why is this characteristic S curve? So, the film if you do this, this is the; this is the characteristic of that film. So, what is that you are seeing? You are seeing some first things first; you have some nonzero optical density, even when you have very minimal exposure, in fact this is asymptotic.

So, that means even without exposure, you already have some optical density, some background level intensities, which is what why it is called as fog level, ok. So, you have fog level, which kind of forms the floor, the lowest value; even though it is, so it is a nonzero value, even when you do not have any exposure. So, that is always going to be there.

So, if you want to build on a signal, it has to be on top of it. So, that is your fog level, we will come to that. Then what do you see; oh then you see a region here right, region here where it starts out. So, for low exposure, you have low optical density; then you have another region, where for high exposure, you have flattening of your optical density. There is no more change in your optical density for any change or any increase in your exposure; then you have a region that is an interesting region that we will talk about, where it is supposedly linear, right.

This whole region where the relationship between your exposure and optical density appears to be linear; that is I can increase the optical density by increasing the exposure, ok. So, we will formally solve this. So, if I have to understand this characteristics, then I have used qualitatively three regions that I have toe spoke about. So, maybe we can formally define how to capture that, that we will do in the subsequent slide.

But the other thing so, you have a toe right; the low exposure low optical density region, the shoulder which is the high exposure high optical density region and the region between your toe and shoulder, where there is a portion which is linear, ok.

Then you have three of these curves here ok; the first curve if you look at it, it is called as high speed film with C a W O; this is familiar right, this is the one that we are talking about right, having the intensifying screen calcium tungstate remember. So, this is your high speed film and recall I mentioned something about high speed; what means by high speed? We will again touch about that the in the next slide, but this should trigger you to our discussion on the intensifying screen, ok.

So, so this is the performance, this is a direct x ray. So, when you have film, that is exposed to direct x ray. So, this will be the characteristic performance. And here you have another optical film, which has a high speed; but it does not have any intensifying screen.

So, we will talk about. So, all of them have the same characteristics, but you notice that each one is shifted, each one is different; you see that each one is shifted with the exposure right and each one spans a different range, each one is linear over a different range, the slope of this linear range is also different.

So, what do we mean? So, we will capture all this and discuss; but what do you desire? You you need to have a good optical density right in the range that is desired, you have to have a optical density for minimal exposure, right.

So, based on that you could already look at it and say look, in order to get the same optical density say for example here; I have to have more exposure for your high speed optical film without screens, right. So, now, it is not just question of photography or anything, now it is biomedical imaging, exposure is a important aspect.

So, I would like to have minimum exposure and maximum output contrast. So, clearly you can see why screen, film screen is helpful and for the same reason you can see why your direct x ray, right. Yes, it is better than your pure optical thing, but then notice that this is very steep right, this is very steep; that means I have a very small range of exposure where I can operate this right, that is what it means. If it is steep, the slope is steep means; I have a very small region of exposure, where I can fine tune and increase the optical density.

After that it will saturate. So, it will. So, you see this important characteristics; that is shifting left right, which has an effect on your for a given optical density, which has an effect on exposure and the gradient or the slope, right. You want it to go tall. So, that you have enough contrast; but at the same time, you want it to go tall slowly, so that you can have more control that will be the desired feature, right. So, let us capture these in the subsequent slide.

So, we are going to use this slide, interpret this slide in the subsequent lecture or a subsequent slides without having the figure. So, make sure that you kind of get a big picture of what we are going to talk about; we are going to talk about this linear region, we are going to talk about fog level, we are going to have effect on speed right and of course your extent, linear over how much range that is also important, ok.

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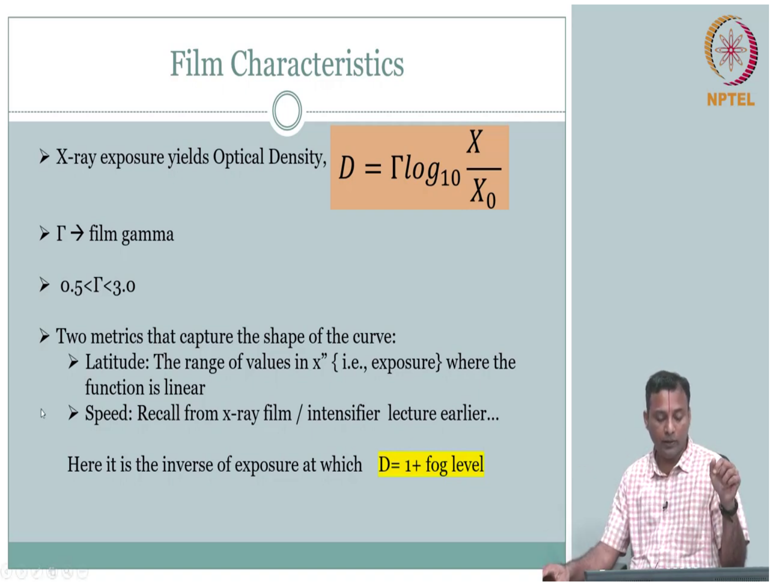

So, what we saw is X ray exposure yields optical density, right. So, we need to connect these two and the curve that we saw H and D essentially connects the exposure to your optical density. So, now, sorry right so, what we need to do is, well the S curve is a non-linear curve, right. So, you, but we are interested in this connection, where we can model and make use of it. So, I can increase the exposure, I can increase the density.

So, yeah where can I model; because the plateau the shoulder and the toe are of you know kind of limiting conditions, I can only operate in between. So, I can model the linear range with the D is equal to this guy which is gamma log 10 exposure by exposure at 0.

What is this? That means, this is essentially saying what is the exposure when I, I mean what is the optical density right when I have 0 exposure or rather sorry 0 optical density, what is my exposure, exposure at 0 optical density. So, this is your exposure. So, all this is fine.

So, it is again logarithmic. What is this? So, this is your gamma very similar; remember I said H and D curve film in a optical photography, you would have talked about this S curve or gamma curve. The same gamma is essentially the characteristics, so the that encompasses that is dependent on all the other aspects, right.

You have to develop the film that, there is a temperature in which you develop the optic that, the dark room; the ambient temperature of the dark room, the chemicals that you use, their p H all those things right, there is so many factors in developing the film. So, all of that put together has an effect and the material that you are using; all of that put together has a effect on moving this curve right, modeling this what you see as the S curve that we saw, the characteristic changes and the characteristic changes due to all possible process are captured in your gamma, ok.

So, that is your film, what they call as film gamma? So, what do you want the film gamma to be? This models the linear range, right. So, ideally you want how do you want? You want, so that the curve you have more region over which you can operate and it has to have tall, it has to have a good dynamic range, ok.

So, typically your gamma you know is operated in the region of 0.5 to 3. So, this is your kind of your slope, right, so how rapid. So, that you saw some of the ah; you saw three curves right, you see the slope that was changing. So, typically the slope is varying in this fashion.

So, your gamma is operational between 0.5 to 3. So, how do we capture that gamma curve? Two metrics, one is just recall. So, what was the thing; one is the one is the exposure range right over which exposure range over which, exposure is in which direction x axis. So, we called as latitude. So, the range over which it is linear, the range of values in x axis which is your exposure, where the function is linear right; you want latitude to be more right, you want more region where you can tune this and then is your speed.

So, what do we know from speed, right? We know speed has to do with, you have light photons coming; the light photons hit the film right, in the intensifying screen x ray photons get converted to light photons, light photons go darken the film so, how far; so more the light photons, quicker the darkening, right.

So, speed in some sense had to do with the efficiency of conversion right, conversion efficiency of the material, ok. So, here what do we want? We want to measure the speed when we talk about; we talk about in our case here, we are talking about the optical, there is a fog, right.

So, that speed the effect of that right, the conversion efficiency can be captured here using the; because exposure to output right, that is what we are talking about. So, it can be captured using D equal to 1 plus for like fog level. So, we can inverse of the exposure at which your optical density is equal to 1 plus fog level, ok.

So, in the previous curve right, the previous S curve for three different things; you saw a fog line which I highlighted and then there was another dashed line, which was your 1 plus fog level. So, the optical density right, optical density D is equal to 1 plus fog level at, here is the inverse of the exposure at which this happens, ok.

So, clear. So, the effect of speed you already saw. What is the effect of speed? You had this tungsten can set screen; that had lower exposure, but good optical density. When the speed was poor or slower, then you actually moved; but in fact speed without right the regular optical film which was otherwise high speed without intensifying screen, that was also required more exposure, because it is start converting, so you have to give more exposure to give more photons. So, these are two important parameters when you select a film for the purpose, clear.

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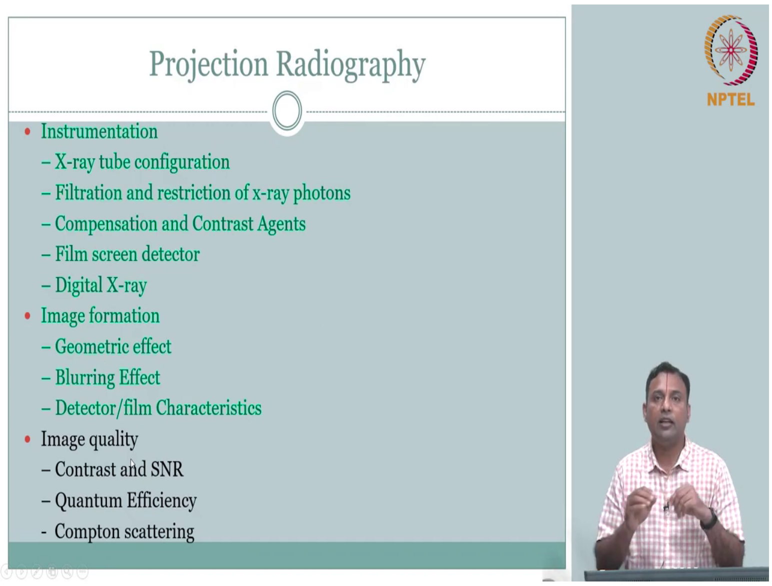

So, I think with that we essentially cover, we have completed covering the instrumentation and image formation. What we are left with now is talking about image quality, the last part. In fact, when we talk when we cover the image quality now, there should not be any material that is new, the only thing that; because we already had a introduction of the image quality and you know what we go after without specificity to any modality.

Even though we did use some examples from X ray, the idea was the concepts on the rational behind what is image quality and the metrics to capture image quality was already introduced.

Now, we have completed instrumentation image formation. So, now, the job for us is to contextualize this image quality metrics to the instrumentation and image formation that we have covered. So, in principle, there should not be any new concept or any new aspect that we will go we are going to introduce; we are just going to start with all the metrics that we talked about, right. What are the metrics we talked about? Noise, signal, contrast, resolution we in some sense we have already covered and we saw the MTF, right.

So, resolution and contrast go together. So, we have to all the terminologies we have covered. So, now, what we will do is, we will rewrite those terminologies and expand them in the context of this particular physics and instrumentation, ok.