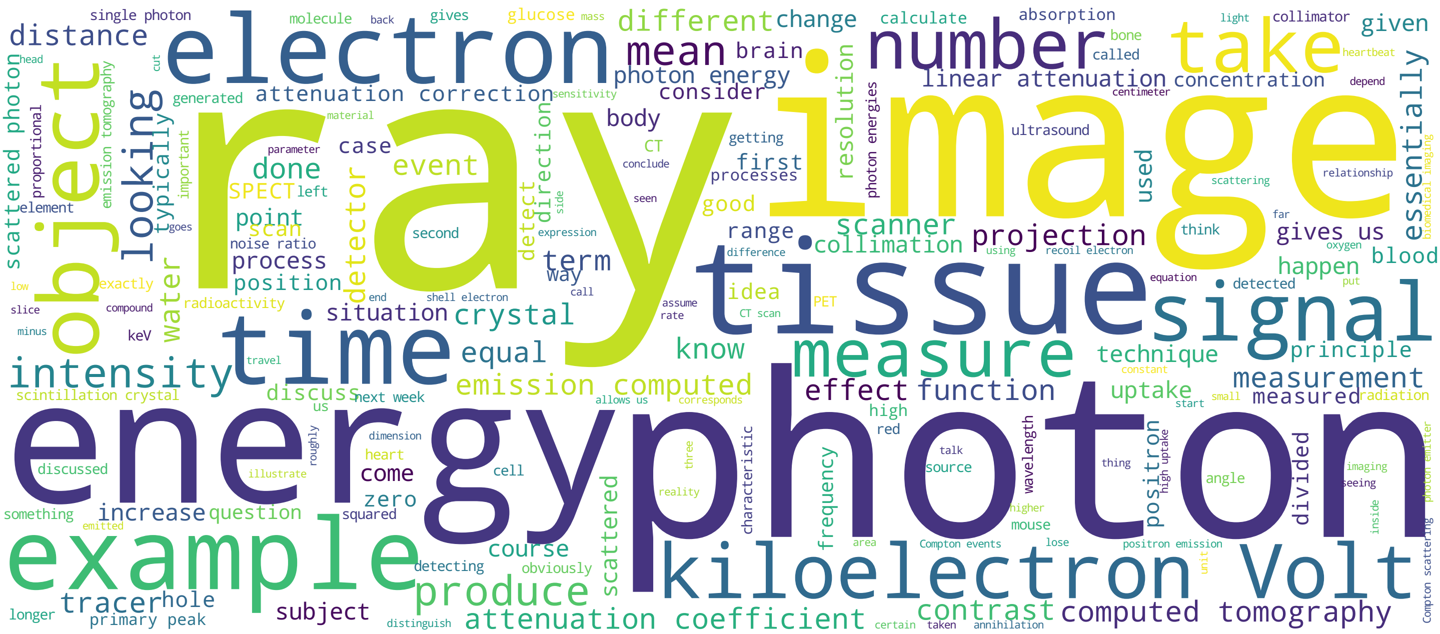
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

5.6 Scatter discrimination & SPECT Summary

Fundamentals of Biomedical Imaging

Prof. Rolf Gruetter



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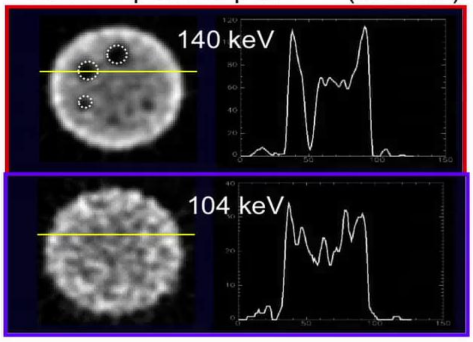
Video

EPFL

5-6. How to discriminate scattered photons ?

Tc-99m spherical phantom (w. holes)



5-16

One process that we need to be concerned with is the fact that photons can be scattered. Let's look here at a sphere filled with water and 99 metastable Technetium and it's got holes in here. These holes do not contain radioactive material. We take along the yellow line a projection so we cut through here, we see intensity here, we see the hole that's here that's represented here by very little intensity. This measurement was done by only measuring photons at 140 kiloelectron Volt. Here are the holes I want to point out. If the measurement is done selecting only the photons at 104 kiloelectron Volt, we no longer see the holes. They're gone. If we take at the same position the projection through, we cut through the image here, we no longer see the hole that we've see here, so it's gone. This effect is similar to the scattering that we've discussed for X-ray imaging, for computer tomography imaging, that increased scattering increasingly masks the contrast. Now, most scattering at the photon energies is done by Compton, so we have a relationship between the initial energy of the photon-- that we know for Technetium, it's 140 kiloelectron Volt-- the measured energy of the photon, which as we have discussed with scintillation, we can measure the photon energy at the angle by which the photon has been scattered.

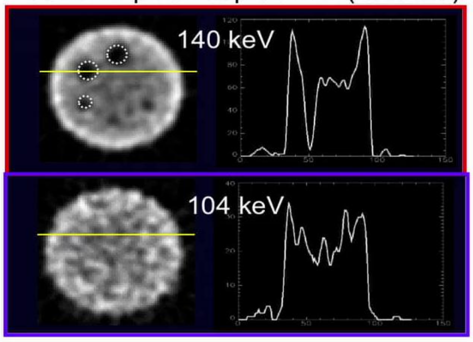
Notes

Summary

0m 04s

5-6. How to discriminate scattered photons ?

Tc-99m spherical phantom (w. holes)

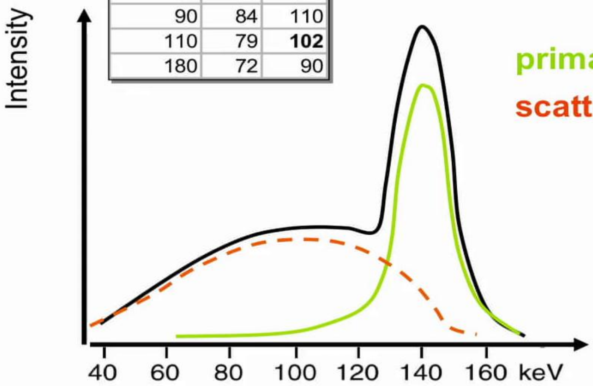


Most scattering is by Compton

$$E_f = \frac{E_i}{\left(1 + E_i \frac{(1-\cos\theta)}{m_e c^2}\right)}$$

Measure E_f
→ identify severely scattered photons

theta/E_i	100	**140**
20	99	138
45	95	130
90	84	110
110	79	**102**
180	72	90



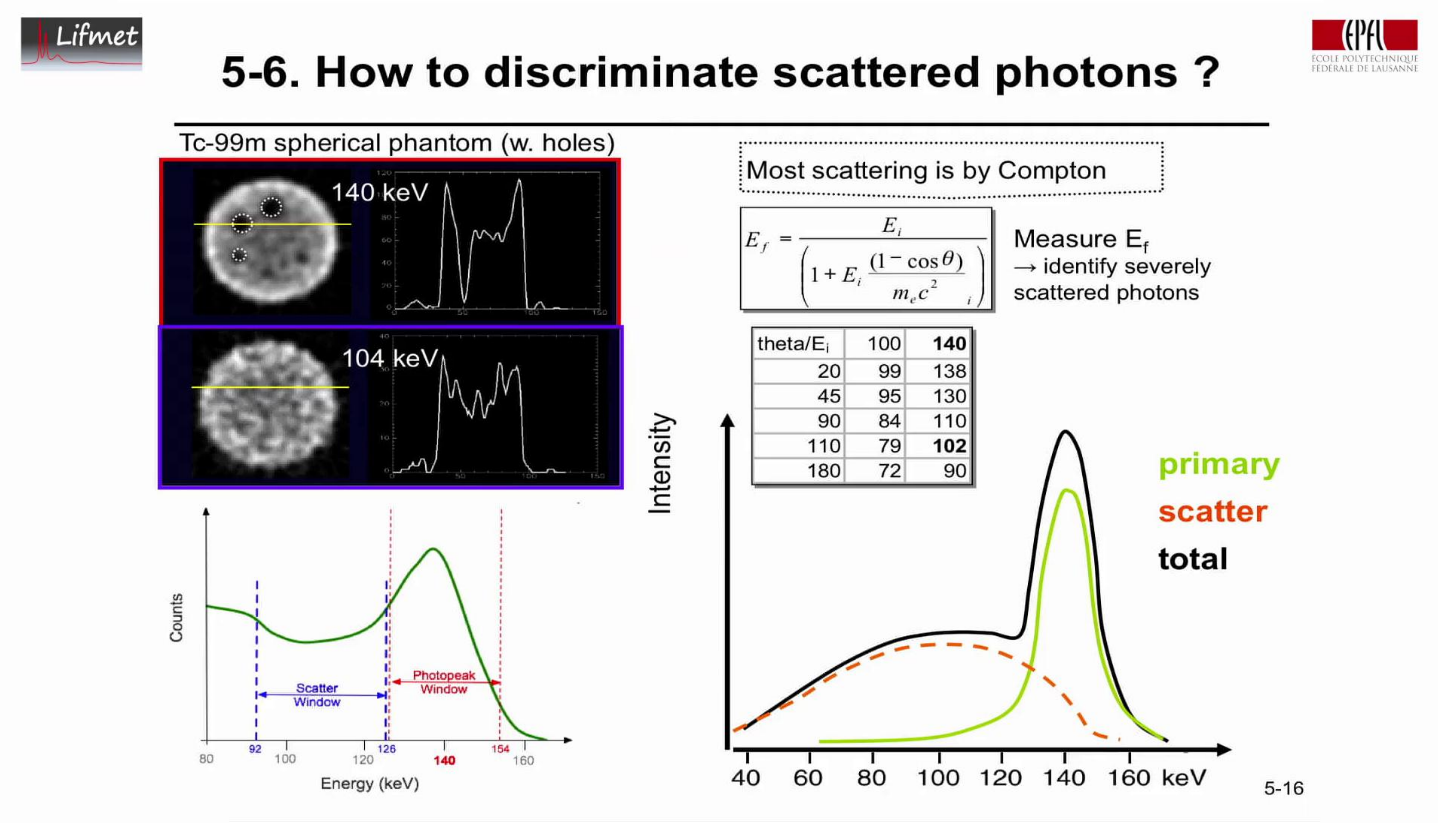
5-16

That's θ here. All that we need to do, in theory, is to measure the photon energy of the detected photon, and with that we can identify scattered photons. A word of caution here: this process is not precise. Let's look at the situation on the left. We have 104 kiloelectron Volts starting out with Technetium 140, 104 kiloelectron Volts, here's 102, that corresponds to a scattering angle of 110º. If we measure here, essentially, all the photons that were scattered by 110º. This is a fairly big angle, and therefore, we lose the original contrast of the image. What is the signal that we detect? We have, here on the horizontal axis, the energy of the photons that we've measured and the intensity number of counts on the vertical axis, here. Now, we'll plot the primary peak, so *that*, we would essentially want to measure. That is the photons emitted, at 140 kiloelectron Volt, and then we have the scattered events here. Those are the orange dashed line. Those are the photons that have been scattered. In reality, what we are measuring from our object is a signal like this. We have the primary, the true counts, the non-scattered photons, and then we have all the scattered photons, that are obviously at lower energies when they are being scattered.

Notes

Summary

1m 38s



$$E_f = \frac{E_i}{\left(1 + E_i \frac{(1-\cos\theta)}{m_e c^2}\right)}$$

theta/E_i	100	**140**
20	99	138
45	95	130
90	84	110
110	79	**102**
180	72	90

And so, our total signal has this shape here that is not just this nice primary peak, but has a distribution. This is the total intensity we are detecting. The images that I've shown you here bordered in red has been taken from the photo peak window, centered on the primary signal here at 140 kiloelectron Volts, and the blue image here, at 104 kiloelectron Volts that was centered on the scattered window, basically taking the energy in this range here, generating the image for photons that fall into this criterion, and the red image was generated by photons that follow this criterion. This allows us to eliminate severely scattered photons. Not every scattered photon, as we shall see shortly, because we do not have a perfect energy discrimination. It's very hard to distinguish a 140 kiloelectron Volt photon from 139 kiloelectron Volt with the technologies discussed in this course.

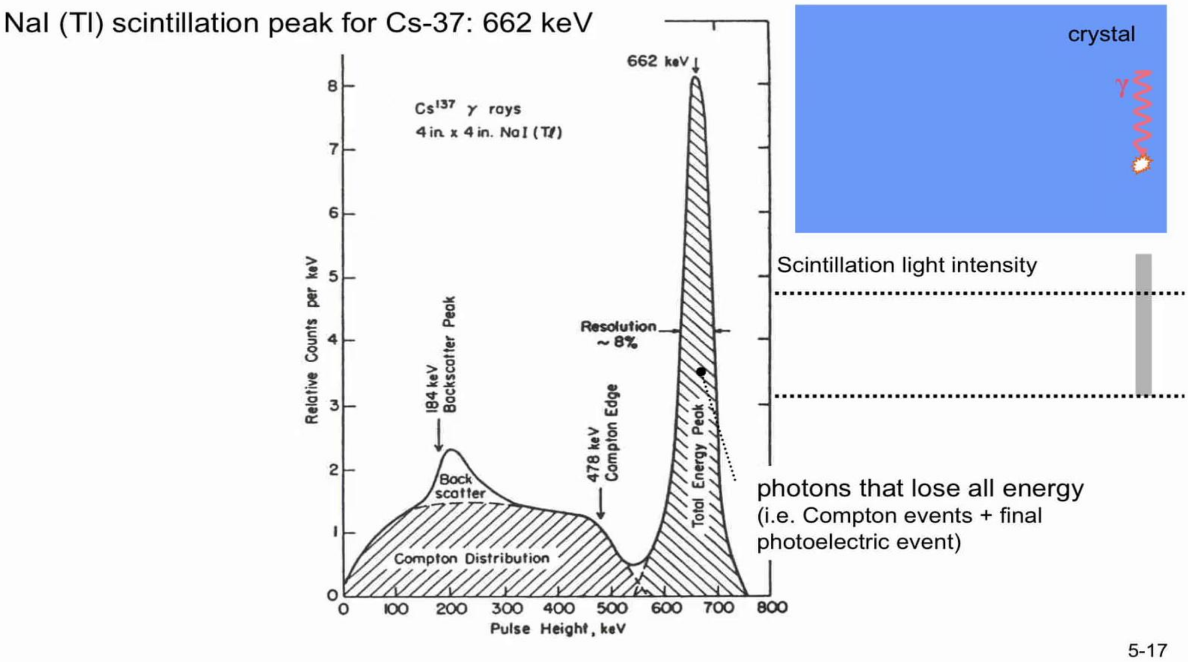
Notes

Summary

3m 10s

What processes contribute to the Scintillation light spectrum ?

scintillation signal depends on x-ray energy

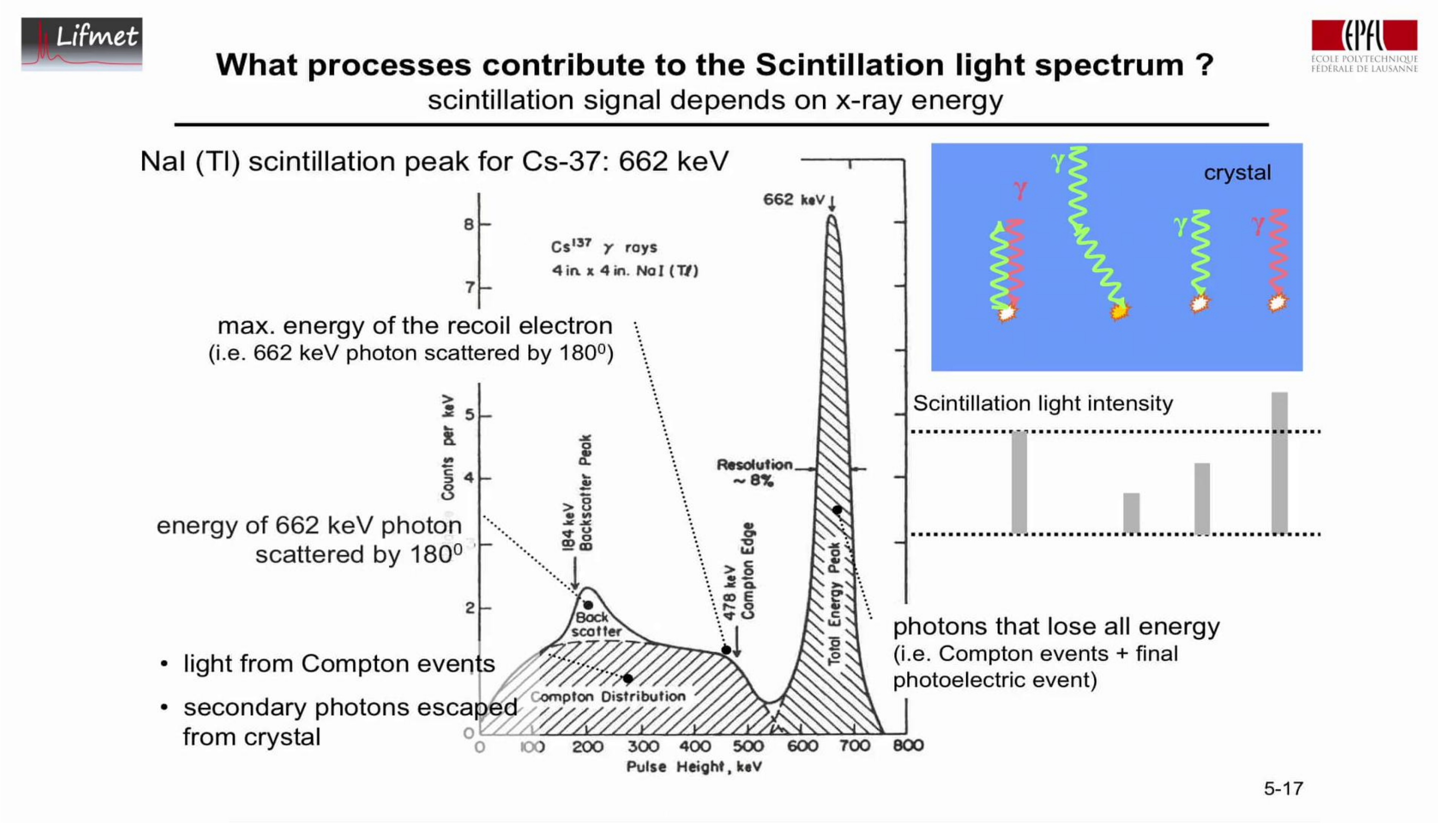


To illustrate a bit more the processes that happen in the body as well as in the scintillation crystal, I want to go over the processes that contribute to scintillation light spectrum. We're looking here at a thallium doped sodium iodide crystal and we're taking cesium-37 here as an example. This is at 662 kiloelectron Volt. This is what you get in data sheet. It's not a very clear single scintillation peak. What happens in the crystal? We are going to look at different events in the crystal. This will be plotted here and we will look at how much intensity this produces. First here at 662 kiloelectron Volt, we have the primary peak. This is due to photons that use [inaudible] of their energy. So we have an X-ray that is plotted here. It comes into the tissue and it loses all its energy to the scintillation centers and they are converted to visible photons. This is, by far, the one that has the most scintillation light intensity. You can also see that this primary peak here has a resolution that is not a Δ distribution so it has a certain distribution, certain uncertainty in measurement, and that gives us an additional uncertainty in determining the actual photon energy of the X-ray that came into our scintillation crystal.

Notes

Summary

4m 18s

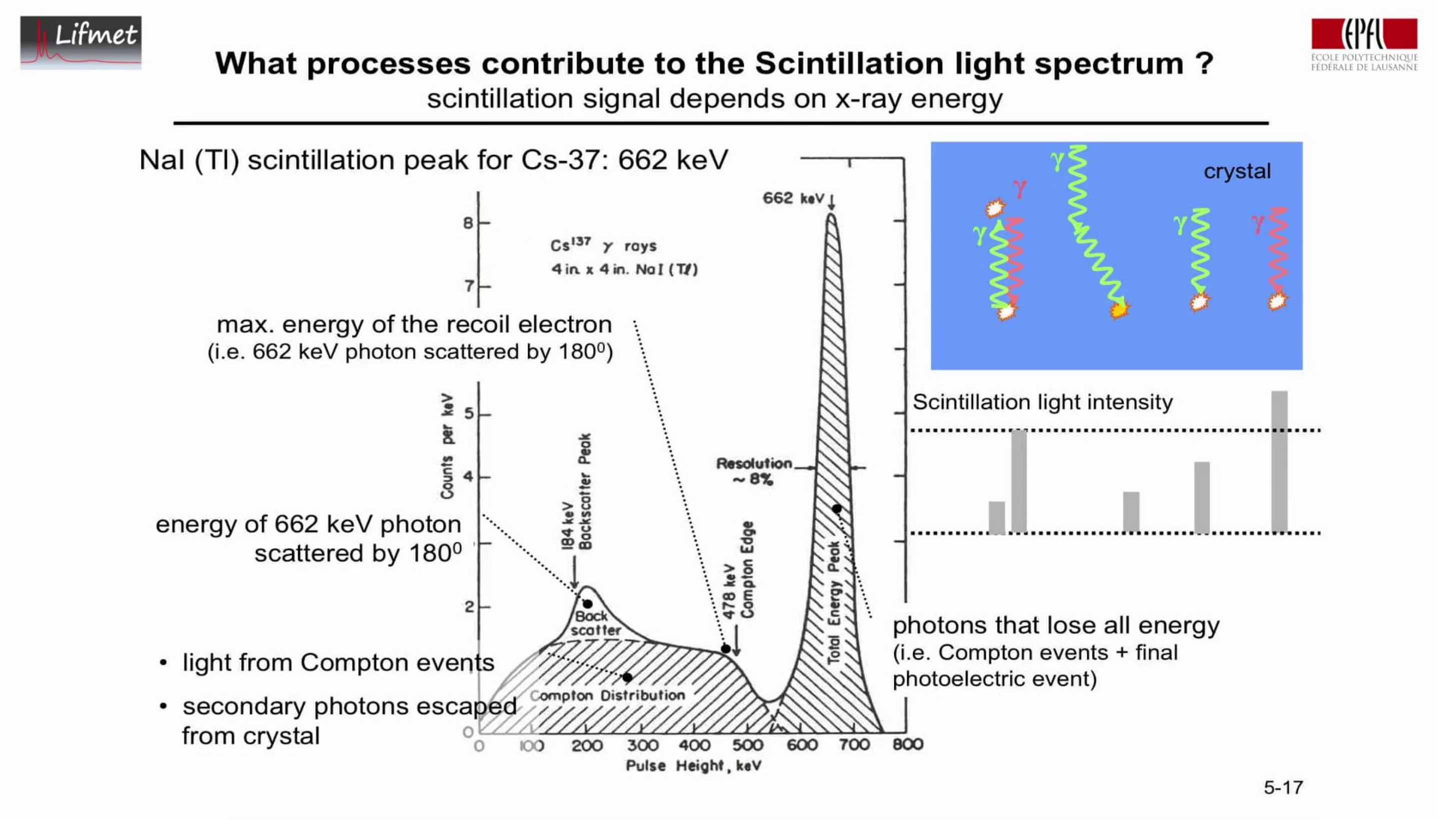


The second event that's characteristic here is the constant distribution. This is from Compton events and subsequent Compton events where the secondary photon has escaped the crystal. Here, for the primary peak it does not matter whether it's generated by one photoelectric event that the electron already is generated by multiple Compton events and a final photoelectric event. Here we have Compton scattering so we have reduced energy. We're not seeing all of the energy of the X-ray and so, this is one case where the secondary photon has escaped or here we have had Compton scattering in the crystal and we detect the energy here, so this gives us this range of energies that we are detecting in the Compton distribution. Then we have this point here which is called "the Compton edge." This corresponds to the maximum energy of the recoil electron, so if the photon is backscattered by 180° it produces a recoil electron and this is the maximum energy, so here the X-ray comes in, it bounces the recoil electron out of its banding and the electron then produces secondary scintillation electrons. Finally, we have also the event of the backscattered photon so the photon that's scattered by 180° that we are detecting here, and that's the backscatter peak here.

Notes

Summary

5m 53s

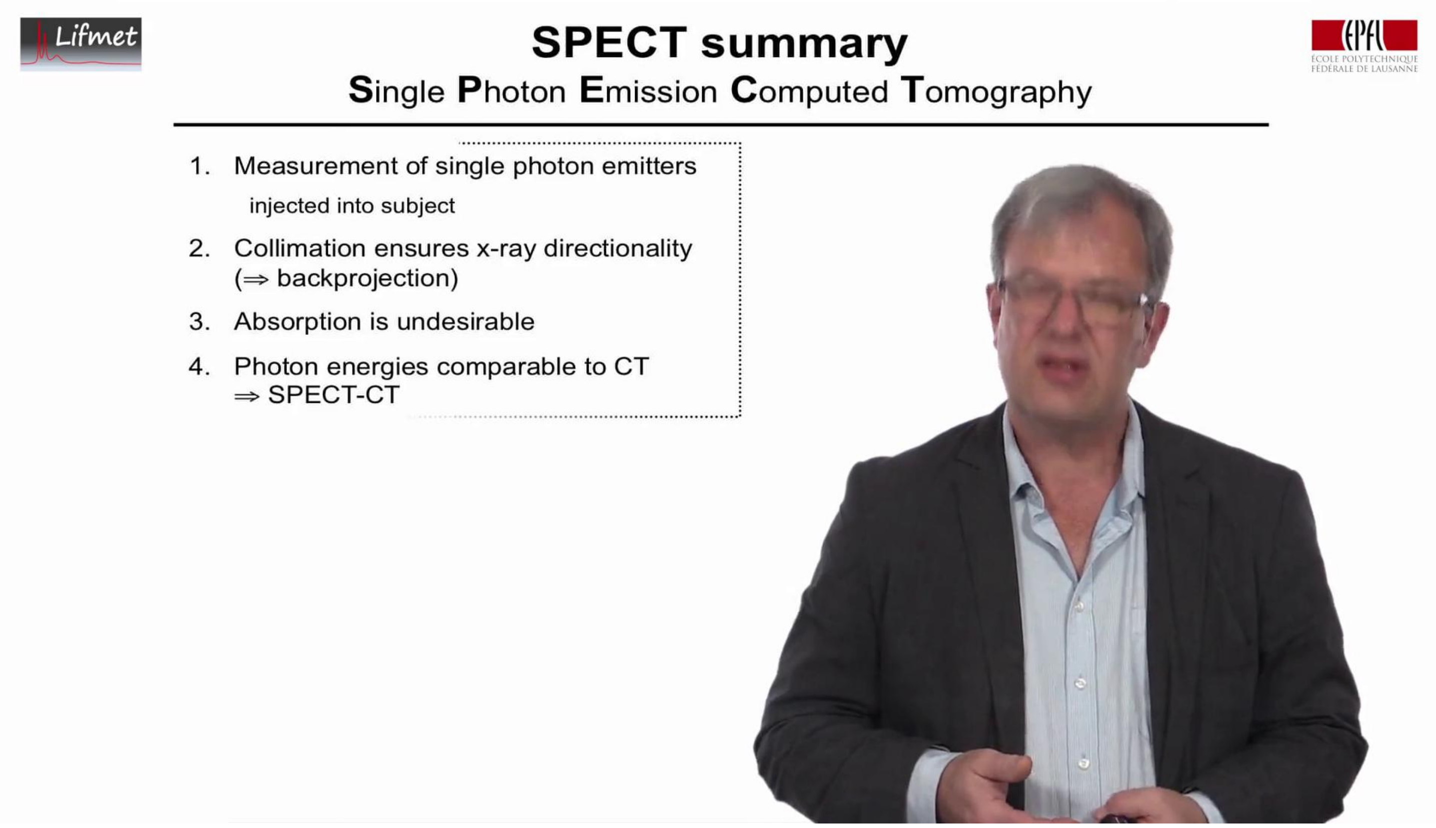


This characteristic. All in all, we have a fairly complex process of a number of events in the scintillation crystal that produce a signal in the crystal. So here is the event that produces the backscatter photon that will then produce another event here and this energy produces scintillation photons. With that, we have talked about energy discrimination. This will be important, especially for next week. We've talked about attenuation correction, some processes that we will be revisiting next week. This concludes the elements of the emission computed tomography section of this course.

Notes

Summary

7m 28s



I've briefly alluded to the official term for emission computed tomography is actually *SPECT, single photon emission computed tomography* and this is basically taking into account that we're looking here at nuclear decay processes, where the result of that is the production of a single X-ray. This means what one does, one measures single photon emitters. They are injected into the subject. We use collimation to ensure X-ray directionality, so the principle here is, once we know the direction of the X-ray, and once we have it recorded along rotating projections, then we can reconstruct with backprojection. For *SPECT*, for emission computed tomography, absorption is undesirable. It's a parameter that we need to consider or try to eliminate. We have photon energies for the tracers, for the photon emitters. They are comparable to the photon energies used for CT scanning, so it is actually not surprising that the industry standard for SPECT is becoming increasingly, or has already become SPECT-CT. You can find the two techniques in one as a detection process. It is essentially the same for both. This summarizes the essential features of emission computed tomography.

Notes

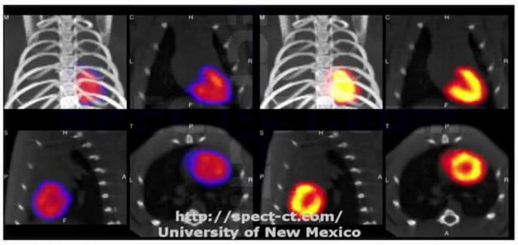
Summary

8m 15s

SPECT summary

Single Photon Emission Computed Tomography

1. Measurement of single photon emitters
   injected into subject
2. Collimation ensures x-ray directionality
   (⇒ backprojection)
3. Absorption is undesirable
4. Photon energies comparable to CT
   ⇒ SPECT-CT



ECG-triggered

5-18

As to the cost of the scanners, it is more expensive than a computed CT scanner. This, of course, varies by country and so on, so I won't get into specific numbers here, but it is a more complex and expensive technology than CT scanning. Here is an example of a cardio scan. This is in a mouse, so we have the ribcage here. This is a CT scan so it gives us the anatomical location and now we can see the heart beat here. How has one been able to obtain images where one sees the heart beat? The scanning process, measuring the emission computed tomography signal takes minutes, so how can we actually separate out the heartbeat-- this is a pseudo-resolution image and what is being done-- is that while the images are being acquired each of the projections. At the same time, the ECG signal of the heart is being recorded and the slices are time-locked to the heartbeat. Then they are reconstructed for each of the cycles in the heartbeat at the same time, and this gives a separate reconstruction and then we produce the images and you loop them through and this gives you the impression of looking at a heart beating in real time. It's not in real time, but it gives you an idea of how the uptake of the trace varies with the beating heart.

Notes

Summary

9m 45s

SPECT summary

Single Photon Emission Computed Tomography

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   injected into subject
2. Collimation ensures x-ray directionality (⇒ backprojection)
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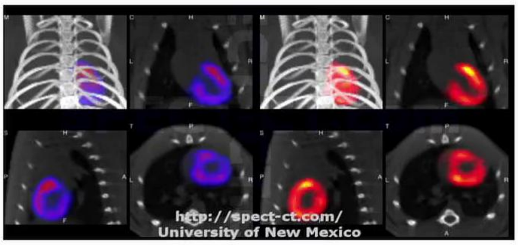
4. Photon energies comparable to CT ⇒ SPECT-CT

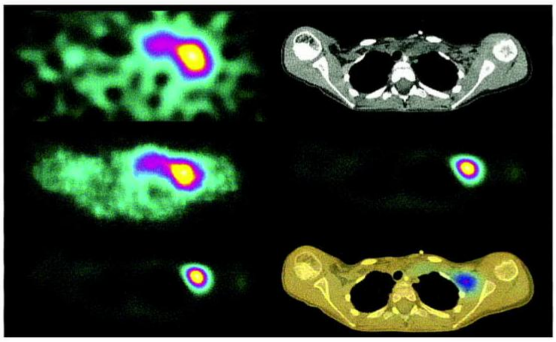


ECG-triggered

FBP

AC

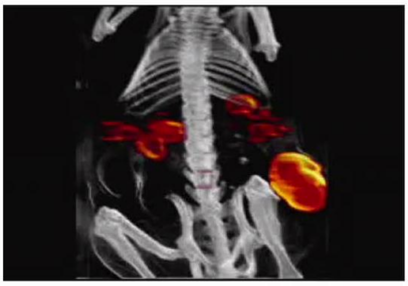
AC + Collim.



CT

SPECT

Fused



Pancreatic tumor (mouse)

5-18

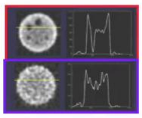
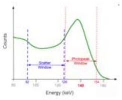
Here's an example from the human torso so we have the filter back projection image. We have the image with attenuation correction, and we have the image with attenuation correction and collimation. This is what we are getting here. That image that's just a blob is the SPECT scan. It's nice to know that we have high uptake, but where is it exactly? So the SPEC CT, combination of CT, here is the CT image, with the SPECT at the same time allows us to fuse the images and we can actually have an idea of where this high uptake area is exactly in the body. This is far more useful than just looking at the uptake itself. In this example we also have the effect of backprojection, attenuation correction, and collimation, how this has a severe impact on the resolution. We would be left to believe here that the lesion is essentially everywhere here, but when we actually look with attenuation correction and collimation, we get the focal point of the uptake very nicely. Finally, the last example that I want to discuss here is this rotating image of a pancreatic tumor in a mouse so this is again a fused image so we have SPECT and CT together. The grayscale shows the skeleton. That's been measured with CT. The color scale shows the uptake of the single photon emitter and here where we see the blob at the bottom is the pancreatic tumor that has been developed in this animal model of cancer.

Notes

Summary

11m 16s

Credits

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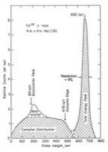

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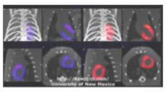

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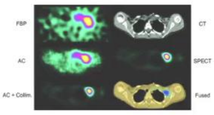
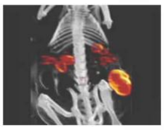


Determination of the Attenuation Map in Emission Tomography
Fig. 12 from Habib Zaidi et al. J. Nucl. Med. 2003; 44:291



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This concludes the emission computed tomography lecture for this week. Next week we will go on to its sister technique that's positron emission tomography.

Notes

Summary

13m 03s