Okay, 12 o'clock now.
Right before this class, I checked with some of you who arrived earlier about preview and review and some of you did review the chapter.
And others didn't say they didn't and partially too busy and partially they kind of like this auditorial type of learner.
And they learned what instructor explained.
Then later on, double check book chapter.
And that way may be more effective or more efficient.
But anyway, so I do think you need to go through material couple of times to understand clearly.
And also when you read the chapter, for example, there is a new clear medicine, new clear imaging chapter.
And some of you side and you feel too much stuff.
And I explained earlier and not all of you in the room.
And we are engineers and scientists or researchers.
So we just focus on BIME course.
We focus on physical principle.
So the chemical principle and the instrumentation, ideas and key components.
Certainly mathematical modeling and quantitative relationship.
So those things are key.
So you get general understanding.
And those like the names of pharmaceuticals and the disease and so on are nice to know.
And also in my PowerPoint files, you keep seeing the right diamond and the green button, that kind of hint you to save your time and convey my ideas about what are most important.
And also, you have to be careful to the central knowledge unit.
And since imaging modality, imaging modality part started.
And I use outline.
So at least you remember the outline.
You know what's important.
And also you certainly still have the green and the red symbols.
So you can see the outline kind of go ahead.
You see what I'm creating.
Do you like put the agents, I think they are a little bit different? The pages wise, I think if you listen to my lecture, and you see those points, particularly you see those slides, highlight the right diamond.
That's your hint.
I really hate to give you specific page numbers.
And also, I remember in earlier, may term causes assessment.
Some student made suggestions and said they didn't feel under the prior requirement through the half of physics mathematics because I used some ordinary differential equations.
And I would argue this way.
And I also know I also serve as supervisor, many undergraduate students.
They asked me about this prior requirement.
And normally I will ask about the GPA and take an overall look and answer the question case by case.
I think even you may some prior requirement causes, like calculus or ordinary differential equations.
Nowadays, it's quite different from say that case ago.
And the partial differential equation, you put it into Google, then you have weak key pages.
You read some terminology, you do not understand.
It is a few click away.
And that may be also called prerequisite means.
So this way I would treat it in a more, much more relaxed way.
As I ask you are willing to learn and do not be limited by what is called page range.
Or text the paragraph or outline or some prior requisite.
And this knowledge is highly interdisciplinary and it ought to be our educational goal.
So you are able and confident independently, I explore around to find the knowledge you need, and link them together to form your understanding of a

particular topic.
So this is my kind of long comment anyway.
New clear physics, they do not notice when we start a imaging modality part, we always have an overall introduction, a general idea, a general perspective, background, and give you a big picture.
Then we draw meaning into key elements, specific to each imaging modality.
And for a nuclear imaging, that's a second major modality.
Likewise, I will give you some general perspective.
And since we finish the foundation part of medical imaging modality, becomes somehow easier, like a story, and I do not feel I'm formally lecturing you, this is a field you just said in my office, if you have some conversation, and I learned multiple times when it's raw material, and I know the imaging modality.
So I have some my own understanding, so it's just a sour information.
And after all, it's a very cool stuff.
So first, again, general perspective, and this is a tiny little bit history.
So any imaging modality, and the world's development, by many talented researchers, and the imaging modality, CTE, IMAI, you know the Garden of Real Price, optical imaging, the Garden of Real Price, and the majority important work, really important work, and the garden highly recognized, nuclear imaging is not an exception, and you look through the milestones in the history, you see big names and many of them, and you can read, I would not read line by line, kind of boring, and most famous to me, I would say, this is Thailand's later Maria Curie, and you can read her exciting story, Garden of Real Price, and her daughter got a very price, it's very cool.
So this is a very important figure in the nuclear, in the physics of the chemistry and the nuclear imaging in particular.
And most of the relevant, with the medicine professor Michael Tepagosin, and he is a pioneer of one of most important nuclear imaging masters called Positron, IMAI, and tomography, we will come into detail later, and I graduated as a PhD graduate.
I look around for Java, and I got hired at my first job in Miley and Crout Institute of Realology, part of Washington University School of Medicine, and St.
Louis.
And I saw as a medical physicist, because I did the SBAO CKA, actually imaging, I really should say desertation.
And I was hired as an instructor, as a medical physicist, I do those measurements.
So in Miley and Crout Institute of Realology, we have a medical physicist group.
The group leader is a professor, Michael Tepagosin.
And I was too young at that time, I didn't recognize how great he was.
This treat him as my small boss.
We interacted very nicely, he is a very nice gentleman.
And later on, it was mentioned by many people, he ought to go to Nobel Prize, for his invention of Positron, IMAI, and tomography, and a lot of pioneering results.
Unfortunately, he died of cardiac disease in Paris, and this is 1996.
And he was the founding editor-in-chief of the ITP-E-Transactants on medical imaging.
That's the most important primary journal in our field.
And he gave me a site of our original slides, the old CT prototype and the field scenes.
I was too young, I didn't pay attention.
I made the place to slide somewhere, couldn't find, that's really pitiful.
And when I seen him, I'm under high-tech experience.
He didn't like new Michael Simeolism.
And he told us, you do new Michael Simeolism, like you simulate a lunch or dinner.
After job is done, you feel even hungry.
So it's very smart and humorous guy.
Anyway, so we learned actually CT, so this is a used reason, gave you some general idea.
Easier you use energy integrating detector or some cutting-edge photon counting detector.

You can record signal in energy sensitive fashion.
So you can solve the x3, hard x3, or re-child.
So you can recognize color in x3 linear tiny wave images.
So that will be very cool.
So you have x3 cells, you suit x3, you can also go into the room, patient, or phantom, and tiny wave, x3 flux, recorded as signal.
You can convert it into light integral.
So you know all about this.
And you date a mat live, I read on, I find beam.
So just review a little bit.
This is x3 CT.
So today, we are talking about quite a different story.
So this is the basic idea of nuclear imaging.
So this principle is very important.
You still have radiation.
But radiation is not from external cells.
It is really introduced into human body.
So radioactivity with artificial, with emitting gamma rays.
The gamma ray and x3 more like similar.
Gamma ray energy range.
And x3 energy range.
They overlap pretty much.
But generally gamma ray range can be little higher.
And both x3 and gamma rays are part of electromagnetic wave while the spectrum.
And they overlap and generally gamma ray considered more energetic range wise.
So you have the internal radiative shots.
And the gamma ray like x3 can penetrate the patient body.
So the gamma ray and the would be collimated by collimator.
Because you want to do tomoravic imaging, you need to know why the photon come from.
Otherwise, you just get a bunch of photons.
You don't know what they come from.
Then you would be unable to make tomoravic images.
So collimator really uses some collimator, like a pinhole collimator or some parallel collimator.
So with the collimator, I only see once again.
So any photon come from, come through the pinhole or parallel collimator.
So I can't determine the directional information.
So for this case, the collimator will light, gamma ray go down and hit the chintelision crystal.
So this crystal will convert high energy gamma ray photon into visible light.
Then you need another layer called photo-multiplyr tube.
Basically, convert visible light signal into electrical signal.
Then there's through some complicated processes.
So the signal gets greatly magnified.
Then you have electrical signal.
You convert electrical signal into digital signal, put it into computer.
That's your data or signal.
Maybe you just take a fine view, there's one projection.
And you take many projections.
Then you have all kinds of indirect measurement.
Then you are able to ask a very natural question and how you can form atomic rocket images like this.
Okay, what the image shows you is the radio-trigger distribution.
It's not an atomic structure per se.
So this is fundamentally important idea.
It is so important.
So let's just add your street data in another slide.
Again, you see this is the parallel hole collimator.
So you make sure any signal you read out here is from this direction.
So the source should be beneath this hole.
So you know the spatial location.
And again, you have a photo multiply, multiply, choose.
And to convert the visible light to signal readable by your PC.

Okay, and once you inject radio-trigger, radio-trigger will accumulate in certain preferable positions or locations.
In this case, you do cardic imaging.
You see how the radio-trigger penetrates, what's a penetrated cardic chamber, muscle wall and those things.
So you can get images.
So you see radio-trigger distribution.
Radio-trigger participated the biochemical reaction.
So you are more looking into biology, or fangousin, physiology.
So this is a highly complementary to x-ray imaging.
So x-ray imaging will have external x-rays.
And the nuclear imaging radio-trigger, see this icon, radio-trigger injected into human body.
And we will go always, bloodstream and circulated throughout the body.
Okay.
The physical principles and the summarized as follows.
Okay.
So unstable, asotope, as tricero molecular, or called radio-nuclide.
And the administrator intravenously or hourly, you can drink a couple of radioactyl liquid.
Okay.
The metabolic process involved the gamma ray emitted from inside the body.
And the measurement really reflect metabolism and the fangousin.
So this is something very different.
And to underline, to underline the similarities and differences.
So I have these right-end direct-end slides.
So on the left-hand side, you see CT scanner and the CT images.
And you are familiar with that.
Okay.
And on the right-hand side, actually, I think there's some problem here.
This looks like MRI images.
And after class, I will exchange this to CT images.
So this is CT scanner.
And on the right-hand side, you have a positive eye emission, puke tomography scanner, so tight scanner.
You got an luminolite triophigilarity.
So once a similarity and differences, and just anytime you work, you summarize them, as follows.
Otherwise, you should be able to do a semicircular thing based on privacy slides.Scosp Studien is between x3, CTs, and Newkelear tomography.
So first, gamma-re and x-ray have similar over-lifed energy ranges.
Okay, then we will see details from your text book and also my proponent files.
So energy level really is really, really really really is the energy levels are quite comparable.
And because the energy levels are high enough, so in biological tissues, gamma-re and x-ray is pretty much ghost-dried.
There are some scattering, but mainly you use a collimeter, mechanical collimeter.
You assume x-rays and gamma-rays go straight.
So that will make tomographic reconstructions a little bit easier.
The visible light that it feels all the way is not very convenient for tomographic reconstructions.
Then the data can be put in the form of line integrals.
But basically, in nuclear imaging, the line integrals are not exactly read-on transform.
Rather, you will see, you will see next Tuesday, I will explain.
That is, I can pronounce a tiny-oated linear integral, and we will guide to that next week.
And the false imaging modalities will present tomographic images.
And the easier linear tiny-oation coefficient of anatomical structures, or just the radio-treature distribution.
But the false of them are two-dimensional or three-dimensional, even dynamic or four-dimensional, A-mesal volumes.
These are similar features.

So we are talking about similarities.
And you need to remember all these.
And in symmetry, so I have the four differences.
We say for x-ray CT, you use x-turn, or x-ray-treature-generated radiation.
But for nuclear imaging, you introduce radio-active tracer into bloodstream.
So the radio-tracer will accumulate more in cardiovascular chambers, or in tumors, particularly the malignant tumors.
They have a lot of vasculature, so they accumulate a lot of radio-tracer.
And some radio-tracer looks like glucose, looks like sugar.
So the new vessels will take a lot of radio-tracer.
And the x-ray CT primarily is for anatomical imaging.
But nuclear imaging, as I mentioned, is for functional imaging, gives you more medically relevant information.
And the x-ray flux can be quite high because you have long paths to penetrate.
So the x-ray flux involved is high, and the spatial resolution is high for x-ray imaging.
And when you take a radio-tracer, and you take small amount for several reasons.
So nuclear imaging emits low-cont data.
So the images, or the data, are very noisy.
So you have the third difference, high versus low flux, and the resolution.
And the nuclear imaging looks not as clear as the x-ray CT image.
And the first of all, the gamma-reflux is very low.
Data is very noisy, and multiple reasons the image do not look crystal clear.
And anatomical imaging, and gives you linear-tenue-resistant coefficient.
And the human body, either the tumor is benign or malagons.
They are all, all consists of light elements.
So they look more or less similar.
So you wouldn't be able to tile difference clearly.
At least you couldn't tile difference early on.
When you got tumor, you first have some molecular level, cellular level, change.
And very small.
And you can see big lump in CT image.
That's later stage, too late to cure the disease.
So in this regard, nuclear imaging is very sensitive.
So any signal you detect from the radio-tracer.
And the radio-tracer will prefer for a day in the tumor side.
And the nuclear imaging can tile a tumor, got a spread around.
And the even tumor is very small.
And the nuclear imaging can pick up.
So this is highly powerful.
And I do believe Professor Tepigal Singh deserves the Nobel Prize.
And unfortunately he died too young.
Anyway, because these two imaging modalities, and CT and nuclear imaging are highly complementary.
So why not put it together? And I know early years, different groups, these cars about this idea, and Simon Chari and the pioneer in putting PET CT together.
So major strands of nuclear imaging is to label most metabolites, how to pronounce it, how to confuse it.
Anyway, I will check the summary.
And the nuclear imaging is highly sensitive to study biomedical processes.
So the nuclear imaging, because the resolution is not that high, and will be in the best form, with CT imaging or MRI imaging.
So CT and MRI give you an anatomical background.
And nuclear-tracer-digit-views will be naturally, precisely, superimposed on the tissue background.
Then the notes take a information content, will be maximized.
So this is a very, very cool thing.
So the PET CT is the first successful example, putting nuclear-seagainer and CT-seagainer together.
So nowadays, in oncological department, and you wouldn't be able to see single PET-seagainer.
They always put together.
And you could argue, you have two-seagainer, and you put an image together.
But in this case, there will be an image-registration issues.

You move a patient around, the image, the patient, the posture, all the things will change.
And also, the skyning protocol, the syrup powder, will be not as good as you have integrated the skyener.
It's a while later on, and the researchers derive the PET-seagainer.
And I mentioned earlier, we are trying to put CT and I'm a together to integrate these two modalities.
But there would be possibility you have a Trinity PET CT, I'm an O-in single machine.
So that will be even better.
So much for this general perspective.
Now we talk about radioactivity.
So radioactivity will have some sections in the text book.
I would say the text is not hard to read, but the terminology is more like confusing to me.
And I'm not a chemist, so I need to read multiple times.
But now it becomes clearer, and they really talk about this physical or chemical phenomena.
And why you have radioactivity? Because the isotop will decay, will I make readations, and it will decay in multiple mechanisms.
And this decay follows exponential curl, and can be modeled using ordinary differential equation.
And not not harder if you just say down to read the relevant stuff.
And this slides you show before, basically review with you about atomic number and the mass number.
And you'll notice you can just review this.
So what is isotop? It isotop of chemical element, and half the same atomic number, but different mass numbers.
So that means they have different numbers of new trends.
They are same elements, so they have same number of protons.
But the number of new trends are different.
Newtron and proton hold together, strong, strong folds, and they are attracted together.
But when you have a different number of new ones, different configures, particularly the number of protons and new trends are large.
And the configures may not be stable.
So while it is not stable, it will change in different ways.
And the radioactive decay will occur following this curl, and we will show that we will derive that later on.
So, radioactive isotop, I made gamma rays and look at here.
So you have x-rays, you have gamma rays, and the detail, if you check Google, the x-rays range about this much, I want to make use of this.
Okay.
These are about this wide.
Okay, this x-ray energy range.
The gamma ray will be some-ho here.
And the gamma ray energy range can be as high as 511 kV, and the data energy level, use the main level party imaging.
And the lower end of gamma ray energy, use the four-spark single photon ion emission tomography.
And anyway, we will know more and more as class goes back.
Okay.
Anz-dabel nuclear changes from higher to lower energy state through gamma ray emission.
Okay.
And the gamma rays have similar energy as x-rays, but are generated differently.
So x-rays rule electron interaction.
Actually, children working principle, you have a e-b-mo-hate tungsten target, and the energetic electrons interact with tungsten, and we will generate x-rays in about 1% is somehow.
Gamma ray really is through isometric transition.
And we will see more clearly how gamma ray generated.
So in your textbook, you will really see the gamma rays really, first of all, say, really the isotol-p, decay in multiple mechanisms.

So you need to understand these four mechanisms.
So called, it's easy to remember, I think, alpha-beta gamma.
Then, in this, to these three decay mechanisms, you have electron-type-tur, electron-type-tur, it's not a cap-tur, it will change.
So this is easy to remember the four mechanisms in your textbook.
So first, alpha-dk, alpha-dk is really means the isotol-p, decay to a daughter, and I made alpha-particle.
So alpha-particle is very damaging to tissue, and cannot propagate a lump.
I think a few millimeters, and you check your textbook.
So this is not used for imaging, rather used for therapeutic cancer treatment, because it damage tissue.
So we hope we direct this kind of particles to cure to kill the cancer cell.
So this alpha-dk is not relevant to nuclear imaging, but this is the first decay mechanism for isotol-p.
The second one called the beta-dk, beta-dk, and really they have two types of beta-dk, and the minus-dk and the plus-dk.
Beta-minus means the electron, and the beta-plus means the positive-tron.
So this is graphically shown here.
And the decay mechanism are defined differently in different types of book or articles.
And some just say beta-dk means this kind of decay by I-mating electron.
And this is also damaging to tissue, the beta-dk, and the first one can be used for treatment purposes.
And the second one, the beta-plus decay can be used for imaging purposes.
And this is really the most important mechanism.
Whereas you have a positive-tron, the decay, so beta-plus decay, and you go from a parent to daughter, then you have an I-mate neutrino and a positive-tron.
Then positive-tron will not stay there for long, and it will capture near by the electron.
So positive-tron, electric, just interact together, will give you a pile of gamma-refer-tons.
So this is a source for positive-tron imaging tomography.
It is very important that you will present more next week.
So this pile of gamma-refer-tons will not I-mate randomly.
They will I-mate in a very correlated way.
So if one more, this direction, the other will go in opposite direction.
So they will roughly form a street line.
So this is a source for pilot imaging.
So some other text book, they just separate this positive-tron, I-mation from the beta-dk.
With beta-dk, they only mean you have decay, giving a electron, then they list another mechanism called a positive-tron I-mation.
And I like this way because I think alpha, beta, gamma, then the electron capture is easy to remember to me.
But for imaging purpose, the alpha decay and the beta-minus decay cannot be used for imaging purpose.
But the beta-plastic and gamma decay, that can be used for imaging.
So you see this positive-tron I-mation.
This is a volatile mechanism to you.
So you have a beta-plastic decay.
This beta-plastic, or proton, and it is positively charged and will attract beta-minus.
This electron will form gamma-re, so you have this gamma-re going in opposite direction rapidly.
The energy level is 511 kV, so x-re wouldn't go that high.
So y, gamma-re, and x-re, energy, ringes are not totally over live.
Yeah, decent to alpha and beta decay, and then we have gamma decay.
And gamma decay, so that means you immediately release alpha gamma photon.
So this shows here, so you change the configuration, little beta.
So this is one way, immediately release alpha gamma-re photon.
Here it's still the same element, but the configuration changed, and the gamma-re photon is emitted.
And the second category is more popular.
So we have the decay, and then we will not immediately give you gamma-re photon.

So it will end up with a metastable state for delayed release of gamma-re photon, and also along with an unpaid neutrino, as shown here.
And the yield textbook about gamma decay, and the use is 99, I'm PC as good example.
And the textbook says, really more aggressively, says no new collide, can decay solely by gamma-reimation, but certain decay schemes result in formation of intermediate spaces that exist in a metastable state.
If you see this formula, you see from a parent to this daughter, and this daughter has a mass-salt decay time, and will give out the gamma-re photon.
So this way is very popular for spiked imaging.
So now you have alpha, beta, gamma, you read the textbook, try to remember these mechanisms.
The last one called the electron-typecher, not a capricent, I will fix that one, and the slice keep being refined.
So this means change the proton to a new neutron.
So here, you have an element excited, nuclear, and you get a electron, that means a electron-typecher, so you get a electron.
If you get a electron, then you will have one more neutron, then you have x-rease or gamma-rease emitted.
And you get a electron, so the nuclear-typecher, you get a electron, and like water, we explain earlier in x-relector, use the term called the Brais-Jolong radiation, and remember I draw some small pictures on this brown board.
And here, you capture the electron, not straight forward, maybe some circualing wave, and pretty much like water, we actually play in the x-relector, and this is a Brais-Jolong process, involving x-recent, dx-recent, and the radiative energy will be given out.
So the gamma-rease, x-rease, these really same photons, this is a different way to generate them.
Gamma-rease will be emitted.
And there are different classification schemes, and this is another example.
So the class A5, I-short-top decay, has five types.
You know R-thar, you know beta-manors, you know beta-plas, you know electron-capitur, and they send, they send, they send, they so-called nuclear-facient, and the textbook they send, they send, it's not so much relevant to an imaging.
So this is what you know, the types of isotope decay, depending on which book we are referencing, but for our purpose, just remember alpha-beta gamma, and beta-you-have-plas-manors, and the last one is electron-capitur, so you know this, you have a rough idea, so far so good, okay? And this table shows you, shows you properties of common radio-treaters used in nuclear imaging, and there are many kinds, these kind of tables, they are not required, and this is the general knowledge.
And we know the radio-active decay follows the exponential curve, so initially you have the radio-active, quantity, or number of elements, and in a certain time later, you will just have half of it, okay? So you have half-life time taken for initial amount, decay to half of the original amount, and keep doing this, and double the time, not half-gang, so keep doing this, and certainly this is the x-pennential decay, just visually you see this, okay? And what's happening with mathematical detail? So why you have x-pennential decay? And like, beer's law, you have x-pennential decay, and when you learn nuclear, optical, or ultrasound, these are x-pennential curve, keeping a period in different ways, and all these due to the fundamental difference of relationship, if the quantity in this case, number of radioactive elements, and the change rate is proportional to the current amount, so when you're talking about the number of radioactive elements, n, so this change rate is proportional to n, so when I will see this first order difference of equation, this solution is x-pennential sin, and like the linear-tenue-son coefficient, you see, one of the material is very sin, so you'll let x-3 pass the sin layer material, then little beta x-3 will be a tinyotid, and that is proportional to certain coefficient, that's a linear-tenue-son coefficient, and we're talking about decay, so you have a minus sign, so depends on how you define the quantity.
You are not talking about how many photons decay, you're talking about how many, how much, what's the number of existing remaining radioactive material, so you have the negative sign here, the solution is naturally the x-pennential relationship, so given the initial number of radioactive material, you have n-

zero, then given time, and you can compute how much material life, so what is the number of radioactive elements, as function of t, and this is modulated by this x-pennential term, with constant lambda, lambda has a meaning called time constant, that determines how soon the decay will be, and particularly we are interested in how long time later, the material will be just half of the initial number n-zero, and you can solve this easily, so you set n equal to 0.5 times n-zero, so then you solve for time, you solve for time, that time is half-life time, half-life, because that means n-zero, is a big certain time later, just half-life, so n equal to half n-zero, then n-zero n-zero can solve out, so this half on the left hand side, half equal to e-x-p-lambda-t, then you perform log, you can find, so the half-life time, then you will easily know how to derive, or you will remember half-life, and it's not lambda directly, rather it's log 2, divide it by lambda, so this is a natural decay time, and when you inject the radio-trisher in human body, then you are based into physical, chemical, natural decay, and also your circularism system, we will try to get some radio-trisher out, like in the urine, you get out, so you have the biological precise, so this decay precise, one part lambda is due to physical, chemical, decay, there are other parts, you can even know physical decay, you can write the first equation, as q equal to minus d capital N, dT equal to lambda prime, and the lambda prime is really the biological decay, and you combine both together, and you have half-life, effective half-life, as a sum of two components, one due to physical decay, the other due to biological decay, biological half-life of radio-trisher, must be also consider, so you can think about how you derive the last equation, if you like, but bottom line you need to know this equation, maybe I should put a red diamond near this equation, so you can deal with the computation of half-life.

So, we are already talking about the third part, radio-trisher production, so we have given you general perspective, we talk about isotope, and we will decay in different mechanisms, and some mechanisms, like a polytron emisson, gamma decay, we will give you gamma-ray, so we can use that for imaging purpose, and the decay can be mathematically modeled rather simply, such as, this N-zero times E to the power lambda t, and what's a half-life, half-life is log 2, divided by lambda, so that's modeling, you can use math-life to draw plots, giving certain parameters, and indeed that's one of your homework questions for today.

So, the third part, we really talk about how can you produce radio-trisher, and the previously we have isotope, it will decay in different mechanisms, but how we produce radio-trisher, and one, most practical popular cost effective method, is so-called radio-nuclide generator, and that is important, and you use the most widely, so we talk about that generator, and the precise is called mild-king, you will know why it is called mild-king, and we use ordinary differential equation to model these mild-king precise, so that's a little more complicated than decay modeling, but really just one more equation, you'll couple two precise together, and you will see how it works.

So, remember how many mechanisms we have for radio-active decay? It's a four, okay? Alpha, beta, gamma, and the electron capture, and the beta-relay, you have a beta-plus, beta-beta-manage, beta-plus is more relevant, so we have four mechanisms for radio-active decay, and I know I asked you how many methods do you have to produce radio-actual toasts, and again, it's easy to remember, also four, so you have four ways to decay, here you have four ways to produce radio-treatures, and these four methods, and data-fold mechanisms, they do not carry the bounds either, this happens to be four, easy to remember, so in your text book, it says, okay, there are four basic methods, four producing radio-treatures, neutron capture, nuclear-fishing, and the charged particle bomb-buttement, and the use of radio-treature generators, so there are four ways, and really I would underline the false method, and other things, we just have a few hands, and we are not chemists, and we don't want to distract too much, and the first two methods, you need a nuclear reactor, so the first and second methods, you all need a nuclear reactor, and particularly nowadays, the nuclear-fishing is more popular, more costly, effective, than nuclear-type-treature, so remember here, you have a nuclear-treature-type-treature, nuclear-fishing, so we say this nuclear-fishing is more popular, and you can't read Google page, I wouldn't read it, but the second, given the needs for nuclear reactor, and we would underline second, the first one, kind of out of date, so the second one is nuclear-fishing, the second method, and graphically shown here, okay? So you can read,

you nuclear-fishing is easier, nuclear-reaction, or radio-active decay-precise, so the nuclear of items split into lighter nuclear-ide, so it will take one, one high-energy particle, then we'll introduce excited states, it's not stable, then split out, then energy, then this nuclear-fishing should not be unfamiliar to you, it can generate a lot of energy, it can be made weapon based on this principle.
Anyway, nuclear reactors, first and second method, are not emphasize, and I really say the circular trunk, and the generator, the third and fourth method, most relevant to nuclear imaging, circular trunk is used to produce FDG data is used for party imaging, okay? So circular trunk, you read, it's kind of accelerator, so you use field to concentrate, accelerator particles, then you can just light the interact, generate radio-trisher, and like a pilot imaging, you really need a dedicated circular trunk, so data is expensive, so this is just the graphical illustration, okay, the third example, and the fourth one, single photon emissing tomography, this is a maximal cost effective, so we take a rise for, let me see, for eight minutes, then come back, I explained the generator, we're talking about how to produce technician, and 99, I'm, and this is for single photon emissing tomography, and you will know more, next part, so take some rise now.
So, we're going to start with the first one, and then we're going to start with the first one, and then we're going to start with the first one, and then we're going to start with the first one, and then we're going to start with the first one, and then we're going to start with the first one, and then we're going to start with the first one, and then we're going to start this one, and then we're going to start at theæ ª coop.
We're going to start at bone value, and then we're going to start with, and then we're going to start at theJevan Classic growth conversion tomorrow.
And that's the residential one.
Okay, so, let's continue.
This generator has a very interesting name here, called Mori-Kao.
This is related to the terminology mild king.
What does that mean? So we look at the detail.
So this pays copy from the text book.
So the production really consists of two steps.
So first you have this 99, I'm all as an initial material.
So put into the device aluminum column and you seal it with some light material.
And you periodically, you certain solution of saline and to just the walls out, you periodically say, every day, you do wines.
So like mild king, you get the radio-trisher out, it's called 99, I'm T.C.
And you have a natural decay time from base material substrate and you got this material.
Once you can communicate on the surface and every day you wash them out, this is your product or your milk in a way.
So this product is used to inject into human body.
Then it will further decay into stable 99, T.C.
And it will have gamma rays generated that way.
So this is too step precise.
And you know from the parents and quantity and one to daughter, this is your product, you get every day and you have a mathematical model, that's an exponential model.
So once you have the daughter, the daughter will decay again.
So this is too step decay precise.
The two decay precise, and you can model both.
And you can see they have different half-life constant.
They have some interesting interplay.
So the dynamic modeling, with daughter, grand daughter, together and you would need three first order differential equation.
So first basically they describe a parent decay.
Then the daughter decay, and the grand daughter decay.
And for the daughter in the middle, so you really have some contribution from parents.
You make a contribution to grand daughter.
So you have the two terms combined.
And how do we solve these equations? And you can just eliminate some variable.

You end up with a single differential equation.
You can solve for N2.
So for N2, then you need to say, and you find how much genius is solution, the particular solution, and you need to review the ordinary difference of equation later beta.
But anyway, it can be solved and put a green button here, if you not sure why you have to find particular solution, how much genius is solution.
What's how much genius is solution? Why these two solutions combined together and determine the real solution, gave the real solution I want.
So all these are very valid good questions.
And I wouldn't emphasize these.
Those are the interesting data.
Just be patient, read a few Google pages, review the stuff, and not that hard.
But if you feel it's just overwhelming, then that's okay.
There's just no, you can model the person.
Anyway, interesting thing, mind-sending in the text book is that, and you see this is dice line, is the patterned material.
The material you put in a aluminum column, so as a substrate.
And the daughter, the daughter is TCE 99, and the gradually, gradually accumulated on the surface, then you may have a bit of weight.
So the precise is modeled in two curves.
So this curve look is very interesting.
So the daughter, the accumulated quickly, because of the given time constancy is for both parents and daughter, accumulated to high amount, then you will decay, and you read some stable results between daughter and the parents.
So the result is pretty much given by the decay rate of the parents, not by daughter, because their time constraints are not the same.
So see this highlighted statement, the result of two spaces is constant.
The decay rate of daughter is given by half life of parents.
Why is that? Because they try to reach the balance.
And then you need to have zero amount of daughter.
And the daughter material accumulated rapidly, the higher and the higher amount, then you decay more and more, because the total amount is high, you decay more.
And the certain point, and it will not increase anymore, it will decay and keep receiving, keep receiving, contribution from parents.
Now the daughter grow big enough, it will decay enough.
So decay from daughter's point, water, water, sea receives, water, sea, give out, I mean decay, will keep the balance, then this result becomes constant.
So try to understand this curve, so whenever you reach this high, it's just use the, use the, it will be losing, losing off the side line, remove daughter as our product, use the full nuclear imaging.
So you can do this, at this time say, 24 hours, you do once, then it will repeat, and it's time because the total amount of parents exponentially decayed, so you got a picture like this.
So this is time instant, you might have to devise a molecule, away you got a partial product, redo-treature, okay, then you got a product, this is not, you'll accumulate all the partial product, that's the total amount, you could guide from this particular molecule, and then you need to change the new color, so this is the working precise, daily yield can be modeled.
So if you couldn't follow all the mathematical details here, and the vice at least, you try to qualitatively understand this mildly precise, okay, we wouldn't require you to solve the equation without looking at the book, okay, this qualitatively, you know, and the parents keep giving out the mean this product, parent keep generating daughter, okay, the daughter also decayed, so when you have input and output balance, then you read the maximum concentration here, then you just take out daughter product, so this is the product from the molecule, you can use that as a redo-treature injected into human body, okay, you keep doing this, so this is a dynamic process, and giving you graduate, it reduce the daily yield, so this way you have a redo-treature and for gamma ray I'm missing, and you can use it for multiple clinical applications, so you have a table, less than Tc, 99, I'm for different clinical applications, so you look through this table, you see from pulmonary perfusion, skeletal brine, so it looks like very wide range, almost all part of the major body part can be helped by nuclear imaging, okay, so much for the third part, so we talk about redo

activity, and we now know what are the four methods, particularly third and fourth methods, the third method for redo-treature really went to positive ionic symptomography, the fourth method is to keep a positive effect, what I say, and the four single photon ionic symptomography, so you heard several times, I mentioned positive ionic symptomography, and the imitated by professor Michael Terprigocin, I mentioned single photon ionic symptomography, what's the difference, so now we talk about the last part for today data acquisition, and data acquisition I mentioned two ways, why is gamma camera, gamma camera, curvature gamma ray signals, so the gamma camera used for single photon ionic imaging, single photon ionic symptomography, coincidence detection, the second one used for poditron ionic symptomography, and what's the difference, the single photon means, you capture a single photon, and as individuals, you use the gamma ray camera, you use the coca-emason, a-m-a single gamma ray photon, you pick up, the second way for gamma ray detection, for the coincidence, coincidence means, in this complex, means two gamma ray photons, are captured simultaneously, and why I have prior gamma ray photons, because I have the poditron ionic imaging, I mentioned to you, so the poditron ionic, and the real data for very short time, we will get near by, near by electron, so poditron plus electron, they interact, then part, part gamma rays generated, they move in opposite direction, and this interaction has a particular name, annihilation is the professional name, so the poditron, electron come together, okay, then become part gamma rays, and you want to capture the pilot, and this code coincidence detects it, and the single photon, pilot photon, color is wanted to gamma ray camera, and coincidence detects it in circuitry, so there is a part of this lecture, and I will walk you through, see how you capture single photon, as individuals, or how you capture pilot, gamma ray photons, as couples, and this will have significant meaning, in scanner design, and image quality, okay, first, let's see, gamma camera, and gamma camera, and this is very important thing, you need to understand general principle, so I put diamonds here, and you showed it before, but here, we're talking about the camera principle, and I briefly mentioned, you first need a collimator, so you don't want to, want to get photons, we don't know where the gamma ray photons come from, with the collimator, only certain direction, and it can be allowed, and actually, gamma ray photons can only go along that direction, so this is quite similar to x-ray imaging, so actually imaging, you record a line integral, so you want to know the line position, the direction, and likewise, the collimator will define line of response, and only gamma ray photons, say here, moving along this direction, can be detected here, recorded here, okay, only this direction, so you know the line-wise information, and why is the gamma ray photon, is the, is the, the, the, the, the, the, the, the, the, the, and the gamma ray photon will interact with the, is the, ah, the, the, the, the, the, the, the, the, the, the, the, the, the, is inside the methy stelltimo vaginaðŸ‘Œ usually feeling like there should be exists but you can't memorize, you need to remember, you can't summarize all theÐ Ñƒ CHR, mutations, never a mention, actually I have numerous kahawajus several layers, and let me just play a step by step so we know little better.
So first thing, the collimation, and you use a heavy metal to block, to block gamma refotons.
So the gamma rear energy is not strong enough to go through in oblique direction.
So we will block the only area to go through the opening.
So this is a mechanical thing, pretty much similar to x-ray imaging.
And these are also collimator considerations.
And also has meaning for selection of gamma rear energy range.
And you don't want gamma rear energy range to low.
If it's too low, it will be observed by body.
You couldn't get a photon out.
If you don't want gamma rear energy range to high, you cannot collimate.
Even oblique rate can go through, hit the crystal and detect it afterwards.
So you have to have good contrast.
This is like x-ray imaging cases.
So all the radio features, the energy range from less than 100 all the way up to 511 all these energy ranges.
And half the property we mentioned particularly for subactivity imaging.
So we want to have something like x-ray energy range.

And for poditron, I'm using tomography.
The collimation mechanism is different.
So now we're talking about the chemical, sorry, mechanical calibration.
But for gamma rear photon, we do not use mechanical calibration.
Rather we use electronic collimation.
I will explain in the final slides what's electronic collimation.
But not just the focus on mechanical collimation.
So you first collimate.
Then you have a since ventilation crystal looks like this.
And pretty much like glass.
When I visited some companies or nuclear detector vendors, and they have the small things prepared as a gift for visitor.
Pretty much like glass.
And these glass are specifically made.
So whenever the invisible gamma rear photon hit the glass and will generate visible light.
So you have glass, you keep shooting gamma rear photons, you could see the flash.
So this is crystal.
Okay.
The collimator can be made in different shapes.
And the parameters determine the imaging performance.
So if you make this dive very deep, then a lot of gamma rear photons will be rejected.
So the signal to noise result will be, the spatial resolution will be high.
But the signal noise result will be low.
So also depends on how deep you are picking up the signal.
So many complicated interactions.
And also collimator design is not limited to parallel hole.
So here you can have a converging collimator.
You can have a diverging collimator.
You can reduce the size of the field view or magnified or use pinhole.
And you can have very high spatial frequency.
If you make the hole smaller and smaller.
But if you make the aperture to small, a lot of gamma rear photons will be blocked.
So the signal noise result will be bad.
The spatial resolution will be high.
You really need to, you need to balance all these factors.
And there are some normal ideas.
And we think, we can use x3 polycapital reliance for gamma rear photons.
Because gamma rear is kind of x3.
They are produced differently.
So there are some devices used to focus x3.
See this green x3 goes this way.
And will be collected and refocus.
So got the highest resolution.
This has been used for x3 imaging.
So if you want to examine radio treasure, gamma rear imaging, this set will have could be also used.
This is a fairly new result.
But it is not required.
It is not in your textbook.
This is for your knowledge.
There are other possibilities to do gamma rear imaging.
Very interesting.
So you can use this kind of collimator.
This is focusing, refocus, and good possibilities.
Okay, so put green button here.
And for signal detection, once the gamma rear hit theå¿ƒty liter or crystal, generally relied, I mentioned to you the flux of gamma rear is very low.
So the signal is very weak.
Then you need this photomultiplier tube to magnify the signal.
So whenever you have a few photomultiplier tubes, they will magnify the signal.

Today is the best day.
So the photomultipotom, the hated surface will generate some e-like trance.
All these days sub-sector to very big e-like trome magnetic potential.
And the photo hated surface generate e-like trance.
And under the patenzo, e-like tronic potential.
So the e-like trance beam intensity will be magnified, today is the best day.
And until the final stage, you got e-like tronic impulse, that can be measured.
So this is the idea how you magnify the signal.
Also convert from visible light to e-like trome.
E-like trome stream or flow of flux and the guidance magnify the stage by stage.
This is the function of photomultiplier tube.
So you really see this icon from gamma rear to visible light.
Visible light through here e-like trance and many e-like trance.
And the form e-like tricol digital signal, the analog signal.
And later on, you can convert it to digital signal.
So this is the signal detection.
You see you report signal.
So this signal detection, you use PMT, photo-multiplier tube.
And there is a relatively long power rifle in your chapter describing how PMT works.
You can read it, but this is the rough idea, like multi-mind signal.
You detect the signal.
So you know there is a signal, but you do not know exactly the signal location.
So signal detection is half by photomultiplier tube.
The signal detection is signal localization, is enabled by the Android network.
And this network kind of message, but we learned the network lecture.
And you know how to analyze network connected by impedance, resistance, and so on.
So you know how to analyze this.
But basically, you know the photo-electric tube.
And they cannot be made very small.
So they have sparsely distributed.
But you want higher resolution.
Once you have resistance here, here.
And they have distributed signals.
And you try to stay made.
Kind of like you have a response everywhere, somewhere you receive stronger electrical signal.
And other part you get relatively weaker signal.
Because all these information you waited, and you are a state made central mind.
And you use the central as the location of the event.
So this is just the analog way to a state made location of this event.
So you see this is the interaction goes through.
And we only show one photo-multiplier tube.
But actually you look at this.
You have multiple photo-multiplier tubes.
So single event may generate output several places, not only one.
So we needed to wait for our reach so that we can estimate to the location.
And we use that as the coding system.
So you know we have signal.
And how strong is the signal? Why is the signal a? So you have all these information to form two dimensional images.
And indeed the two dimensional image has a name called the Planner Synthetix.
So this is like actually projection.
And you do the same thing as the plane.
This is another view.
And you have a piece of a gallery camera.
Looks like this.
And you have a patient inside.
There is a child.
Or abdomen.
You have radio transmission distribution.
That's through multiple layers.
And the base signal detects and localization.

So you can form a two dimensional image.
You know the signal, the drawings, and the location.
And the photo-multiplier tubes together will form two dimensional images.
And we will be as useful as the X-3 radio graph.
And you take the test, the X-3, you do my mockery, this is one view.
And indeed I know some researchers, they dedicate some special Planner nuclear image for bright imaging.
So the idea has been explained, but I just repeat here, with a little bit different view angle.
And so first layer, you callinate gamma rays.
And you can work gamma photon to light.
And you can work light photon to electrical signal.
And you can work with a multiple layer tube.
So the visible layer, you need to see the precise inside the tube.
And you have multi-stays.
And the easiest days you have, you see more and more electric signals.
And driven by strong electrical potential.
And finally you output the analog signal.
The analog signal goes through logic circuit to give you location information.
And you have a pulse height analyzer.
You reject those even due to multiple scattering.
And whenever the signal goes through the scattering precise, the energy level will be reduced.
So the gamma ray photon wouldn't be that powerful.
So when the lower gamma ray photon interlocked with crystal, and will not generate as strong electrical signal, so the height of the electrical signal wouldn't be that high.
And then you can set some threshold to reject the scatter induced signal.
And you gated the signal, maybe you do physiological gating with cardiac motion.
So your only concept signal when your heart is at the largest volume or smallest volume.
So it's just a gated signal, put it into computer.
The gating can do EKG gating.
So you know heart is the key beating.
In the right state or in the risk certain cardiovascular phase, your only collect signal at the given phase.
And you will remove the motion artifacts.
So this is overall picture.
How to take one view of nuclear treasure picture.
And this is the same place similar role as the x-ray projection.
And for tomographic imaging, you need many views.
And I wouldn't mind that today.
And we will mind next week.
And the pulse height analyzer here.
I explained a little bit.
Let me just clarify further.
So talking about x-ray, gamma ray energy spectrum.
So if you have radio tracer there, you put a camera on, and you guide the energy distribution.
The spectrum, gamma ray spectrum will look like this.
And due to some light x-ray peak, because you have a kilometer, and you have the TC-99 I'm.
So you have the relative count as a function of gamma ray energy.
So you have the curve like this.
But if you put a patient, and put a patient in front of the camera, and the inside of the patient, you have gamma ray radio tracer.
The gamma ray will be scattered.
The same thing, gamma ray like x-ray, and mentioned that you have a competent scattering.
A lot of scattering.
And the competent scattering, the easiest scattering, you have the larger angle, the lower energy.
So you have all of the scattered gamma rays.
This is like scattered x-rays.

You will have a cloudy appearance on top of generic signal.
So you have a special, somehow like this.
This is why we need this one.
The power is high analyzer.
And the power is high analyzer, and they can determine the gamma ray energy range, according to electrical power amplitude.
The higher energy, usually the higher energy, will interact with the crystal.
We will generate more visible light.
More visible light will generate more electrons in photo-multiply tube.
And we will generate stronger electrical signal, so greater amplitude.
So if the amplitude is high enough, the signal energy will be at least 130.
Oh, this is 150.
So if we are waiting this range, then you will accept as useful signal.
If the electrical signal is only low, below the threshold, then you can, you can infer backward.
You see the initial gamma rays interact with the crystal, and it is only about 100 kV.
Why is it 100 kV? Because Tc 99, I made monochromatic actually sounds like that of A13, I couldn't remember, but some higher, maybe say for example, 130 kV.
Why I expected to see a gamma ray of 130 kV? Why we have 100 kV gamma ray? The reason is clear, because the confidence scattering, because the initial primary gamma ray, scatter the multiple times, lose the energy, degraded to gamma rays 100 kV.
And this is 100 kV gamma ray, and we will not generate that strong electrical signal.
So we reject that signal.
Let's place the same role as the anticeguetry engraved.
In terms of point spread function of gamma ray camera, ideally, so this is the intrinsic crystal resolution, and the photo-moutain plier tube, and all these factors together, you have a Gaussian-like point spread function.
But if you have a strong confidence scattering, that will make the tail quite accidently.
So this is not good, then we need to reject confidence scattering.
So this is the concept of point spread function and spatial resolution.
The point spread function gave you indication on how good the camera spatial resolution is.
The supper point spread function, the better spatial resolution.
And the spatial resolution depends on multiple factors.
Again, this is copied from your text book.
I wouldn't read it, you can read it.
It's easy read, or just qualitative discursion.
And quantitatively, you have the last line.
The final system resolution is the combination of intrinsic gamma camera resolution, and on top of gamma camera, you put a collimation, a collimator.
The collimator will modulate the resolution, and also, competent scattering will further degrade the spatial resolution.
And the easy precise, you consider independent.
And just like you have three random variable, easy random variable, you have a spread, okay, you have some spreading, some blurring effect.
You have your either three random variable together, you have a over or over random variable.
And the variance of the total variable will be the sum of variances of the individual three random variables, because they are independent.
So, like by same reasoning, so you compute the resolution by sub-squire, squire the individual quantity, sum together, and then you get squire root.
So, this is like you have two or three random variables, you have a standard deviation of the sum.
You really need to find the variance of each individual random variable, okay.
And the variance means squire the deviation, by them together, then you squire root, same idea, okay.
And another interesting issue, I would like to explain a bit to you about that time.
And say you have a crystal material here, and you got a gamma photo, interlocked with crystal, then you have a pulse generated.

The pulse is not infinity, so you have certain values, okay.
So, if you have too many gamma photo, all jump together, and the system cannot count, like a photon counting detector, actually photon counting detector, you have a counting rate limit, there are too many things together, the detector or gamma camera, can now keep, keep, place, place, even.
And this is like you count how many candies you got from a ceiling, so you can keep dropping candy, you can count.
But if you drop too many, you couldn't count, this is likewise, so here you could, by the time, and this is something, and it encourages you to think how you derive this time.
But what is capital, capital is true counter rate, suppose you have ideal counter, like god's counter, so anything comes, this is the kind of perfect, okay.
And the location is opposite of the counter rate, so the camera is not perfect, it may count 99, but actually really you receive, say, 150 gamma photo, but you detector is not perfect, if you have two, two gamma photo, come together, this is counting as 1, because this is the kind of tile different, so you have capital and the lower case, the time is defined as increasing, 2.17, why you have this difference, and it's multiplication in denominator, why is that, give some thought, so this is the idea.
And say, you cannot count that many, so you need time, you count, you count the rate, okay, the counter rate is, and then the related time used for the opposite of the counter rate is racially perical, that's just the average, for example, you say, it's a opposite of the even, how long time you spend, and it's not number, it's counter rate, so you use the racially perical, that's the time period, you spend to count, observe the event, but in reality, what's the period of true gamma-referre times, you have true counter rate racially perical, that's the real happens, you have uneven, uniformly spaced, you take it, it's much time, the difference, and the opposite of the counter, take a longer time, then the voltage really happened, so this difference is, it's time to time, so you need to think about this, and like the, like the morally called modeling, the dynamics, like this definition, a few things, and if you didn't review, you just follow me, you may not, and you should not, naturally you should not follow everything I said, but you can think afterwards, hope you will understand, and I will update the slides and upload tonight, because after lecture I need to see my kidneys don't doctor, so why I couldn't update immediately, and any question my office or Monday, Monday's same time, and now we talk about the FDG, for cancer imaging, FDG is a radio tricer, and the produced by cyclotron, okay, it's not a force measure, you certain measure to produce the FDG, and the FDG, and we will do, you remember, beta plus, we will animate polygytron, then polygytron will combine with a electric, then you will have a part, part, the gamma ray emission, so polygytron emission, or beta plus decay, is the physical or chemical basis for part imaging, polygytron emission tomography, so this is so important for cancer imaging, and the cancer is just a major disease, when third of us will have cancer sooner or later, then beta imaging becomes very relevant, and we will need to do co-incident detection, idea like this, okay, this is even, even we will generate part of gamma ray photons, so if one gamma ray photon accepted, I mean one gamma ray photon detected by this crystal, and then goes through photo-multiply tube, got electrical signal, and magnified, and you do, remember this, pulse, height, analyzer, you just make sure, it's not too low energy, and it's not too high energy, so that we know it takes the gamma ray photons, produce from the annihilation here, so you got one pulse here, and on the other hand, it happens to have a system, a corresponding arm, and detect, detect the system, gamma ray photon, then you have a pulse, goes through all the process, so you have two pulse, they happen, they travel similar distance, and they all come back to this co-incident detect circuit, and then if from, lifetime, right arm, same alternatively, I got two, you like, you like, electronic pulses, and the, the, the, the colleagues bounding to 500, 11kV gamma ray photons, if we receive two together, then I have reason to count one, that means there must be one even, along the line, they find by the power of detectors, so this way, and we report, even the two gamma ray photons, detect the, together, see this arrangement, we really look for power, the pulses, and we do not put my chemical columnite, and the circuitry is complicated enough, so we look for co-incident, and for any part of them, these are, this part, or the

upper any of them, so the circuit, and not just the single circuit, it's really not work complicated circuit, and we are, watchful, interested in any firing, so arbitrary draw line from, detect the element i, to detect the element j, as long as you report, co-incident, I would, info will report, I would report, there is even happen along this line, so for any detect unit, you keep having, you, you, any interaction from single detector, and then we have, electrical signal, any electrical signal, we recorded as a function of time, and then sometime got a pulse, other time got basically, ground flow noise, it got a pulse, it got a pulse, and then any of them got this, and then any tool of the detector, you're looking for co-incident, if the detector, detect i and detect j, at the same time, they got a high amplitude, the calories bounding to 500, 11 kV, that I would say, okay, between i and j, there is a response, and between i and j, there is a response, it could be here, it could be here, any wire, I don't know, so, coding to this co-incident detect, then, they can be along, up, along the line of interest, any wire, so this is a traditional way, to detect the power of gamma-ray, and more than once, the way they are picky about a rival difference, and the lifetime and the right arm, they receive the signal, not exactly at the same time, they arrive with the tool rivals, have a slight time difference, and based on that, they say you take a longer time to reach my right arm, then, my shorter time, to my life arm, so I tend to think that even, it will be closer to my life arm, life arm detector, so in this case, you take the time of flight information, into a constant reason, you will have more information, to localize the event, not only along the line, but also wire along the line, not only the line of response, but the reason, the interval, and you have a high likelihood here, no chance at this direction, it must be little closer to my life hand side here, because I have time difference, the other measurement are not exact, so you have uncertainty involved, that's why you have distribution, so without the time of flight information, and you'll try to buy it, you will something like stop at it, but the reason, time flight information, you can improve the tomography resolution, little bit better, so this is idea, the idea wise, not hard, so you need to know, however, and your homework, so from your textbook, the first fall, and how you review, basic concept, and the dual data similar, and you are not limited to only these four questions, and you feel free, read other questions, and you have questions, you ask TA, ask you instructor, this has visual student, but these will be graded, not limited to these questions, so much for today, okay? I'm going to start with the first one, and then I'll start with the first one, and then I'll start with the first one, and then I'll start with the first one, and then I'll start with the first one, and then I'll start with the first one, and then I'll start with the first one, and then I'll start with the first one,