Neutron Scattering for Condensed Matter Studies
Center for Distance Engineering Education Programme
Indian Institute of Technology, Bombay
Lecture 8A

Keywords: In-pile collimator, Gamma ray filter, Single Si crystal filter, Inner gate, Soller collimator, Be filter

In the previous lecture, I told you how we will tailor made the beams inside the reactor and how we can transport the beams outside the reactor and even outside the reactor hall or target hall using guides. So, this is about neutron transport from the core and to faraway places.

In this lecture, we will be discussing the various components like filters and the collimators that are used in the beam line and also the kind of monochromator we use in tailoring the neutron beam. These are in next part of the lecture, where the beam tailoring with respect to wavelength and with respect to removal of unwanted components are concerned.

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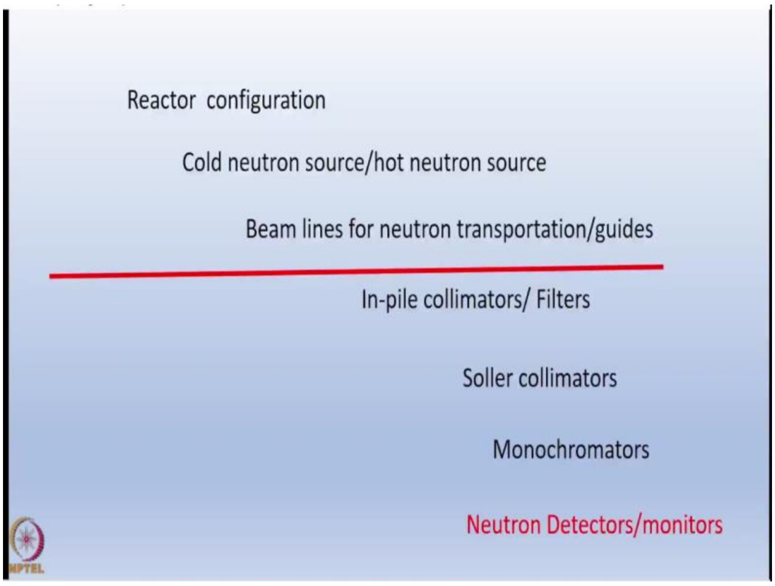

I have discussed with you in the previous lecture up to the beam lines and now, we will be talking about in pile collimators, filters, soller collimators and monochromators. And at the end most importantly I will take one lecture on neutron detectors and monitors that are used at various sources.

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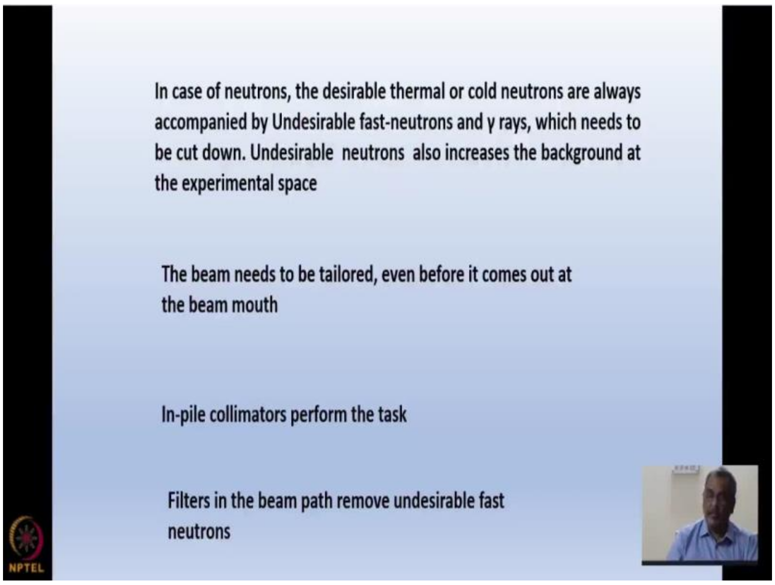

In case of neutrons, as I am harping again and again, along with the desired thermal or cold neutrons with which we want to do the experiments are always accompanied by a lot of undesirable fast neutrons and gamma rays and we need to cut them down.

We need to cut down the neutrons because, if I have neutrons, which are not so harmful to health, but it can be harmful so far, the experiment is concerned, as it will increase the background in the experimental hall. Hence, the beam needs to be tailored properly even before it reaches a monochromator and also be tailored after the monochromator, before it reaches a sample.

So, before the beam reaches at the center of the monochromator drum, in-pile collimators are used to cut down and tailor-made the beam. It filters the beam, so that unwanted and undesirable components of the beam can be removed.

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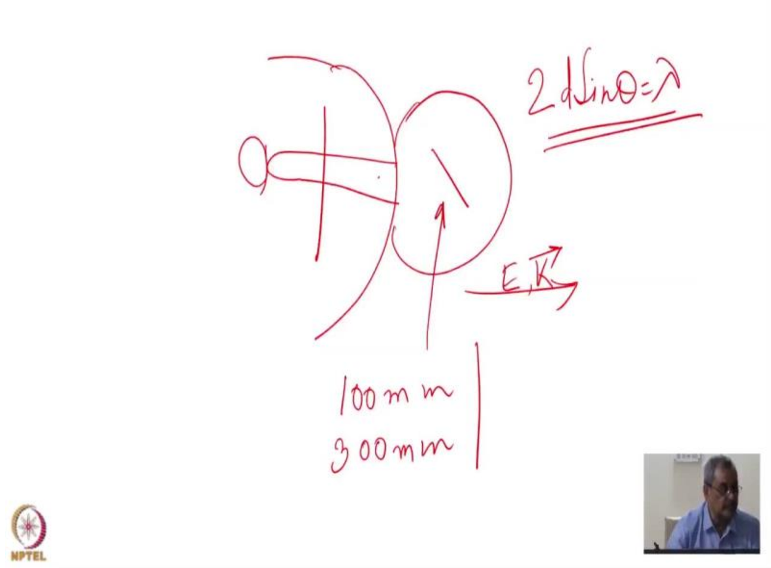

Consider this beam path, the core is somewhere here and there is a large monochromator drum. It is a drum because it needs to be rotated and at the center of it there is a monochromator. Monochromator reflects the neutron beam and chooses a monochromatic wavelength because in scattering we need a defined direction and energy. The beam hole before the monochromator can be as large as typically 100 mm to 300 mm (diameter). It is a large beam hole and we should have the facility to close down the beam because sometimes you might have to approach the beam hole and this is directly open to the reactor core and very strong radiations can come. So, you should have some way of cutting down the beam. All these come inside the beam path, known as the inner gate and another component, what is known as in-pile collimator.

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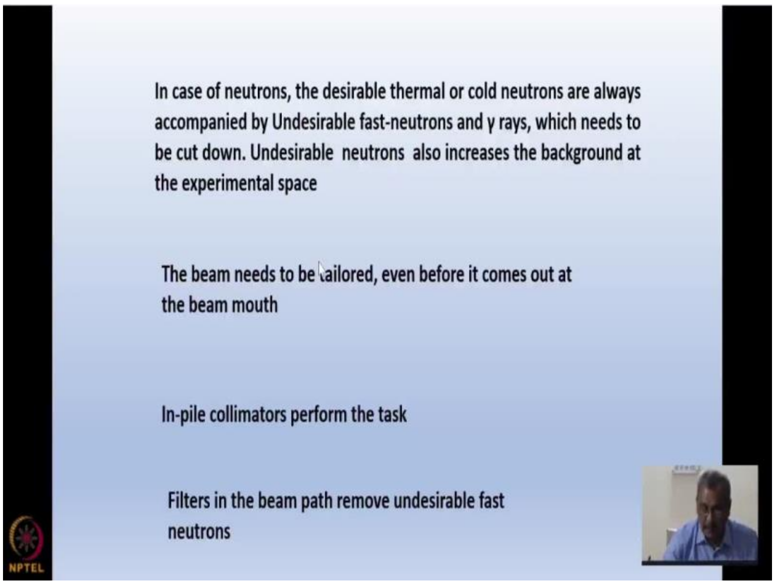

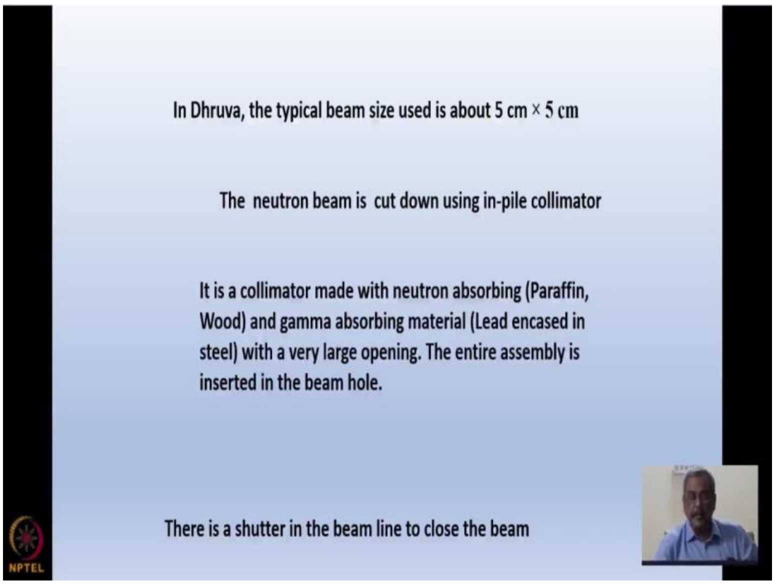

After you have removed the harmful radiation, we also need filter in the beam path to take out the undesirable components of neutron. Moreover, neutron flux being low, so, we need to have a large beam size unlike x-rays. This is the biggest difference I can give for the beam that physically differs with a synchrotron source.

For example, when you are working in a synchrotron source, the synchrotron radiation which is coming from an accelerating electron beam is highly directional. Few microns size beam comes out and of course, it needs to be monochromatic You can compare this with a neutron flux of 10^{14} n/cm^2/sec in the core that has come down to 10^7- 10^8 n/cm^2/sec at the beam hole mouth. Normally, case of neutrons we will be using a beam as large as 5 cm × 5 cm.

Hence, the neutron beam is first cut down using an in-pile collimators in the beam path. In-pile means it is inside the pile that is, it is inside the biological shielding. So we take out only neutrons beam of that size which is desirable, rest all we tried to cut down right inside the beam tube.

This collimator is made with neutron absorbing materials e.g. paraffin, wood and gamma absorbing materials like lead encased in steel with a large opening, large opening because we need to have 5 cm × 5 cm beams typically. It can be slightly smaller in a reactor with higher flux. And there is a shutter in the beam path to close the beam.

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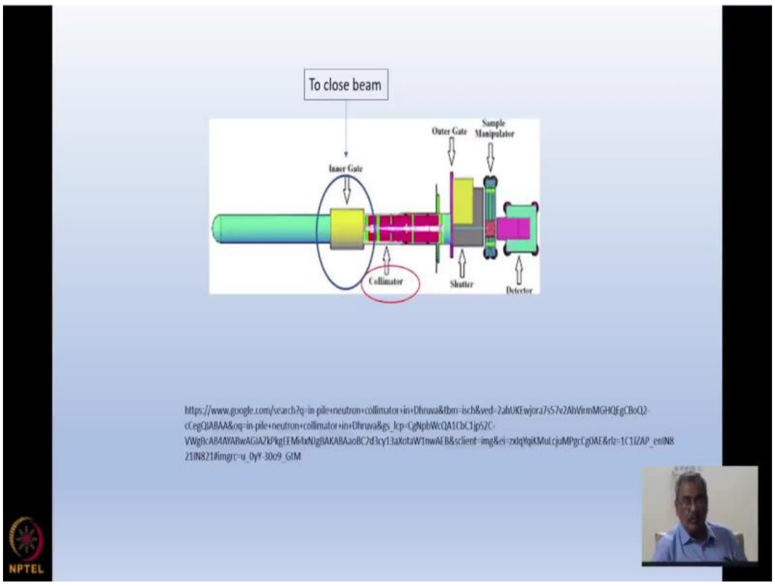

I show you a schematic of a beam line. So far, I have showed you the beam line just as an opening hole going all the way up to the core. But now, in details, I show you that this beam line has got an inner gate. This inner gate can be closed when wished so that the beam does not come out and we can approach the experimental spaces. There is a collimator. This is an in-pile collimator, (orange color) and then there is an outer gate right at the beam hole mouth. We have a gate that can be closed, and there is a shutter for that. Then we have something called a sample manipulator and detector. This is taken for a neutron imaging beam, so, this part you need not bother. I just want you to concentrate on the beam geometry: the beam comes out through the inner gate, then we have got a collimator and we have got an outer gate.

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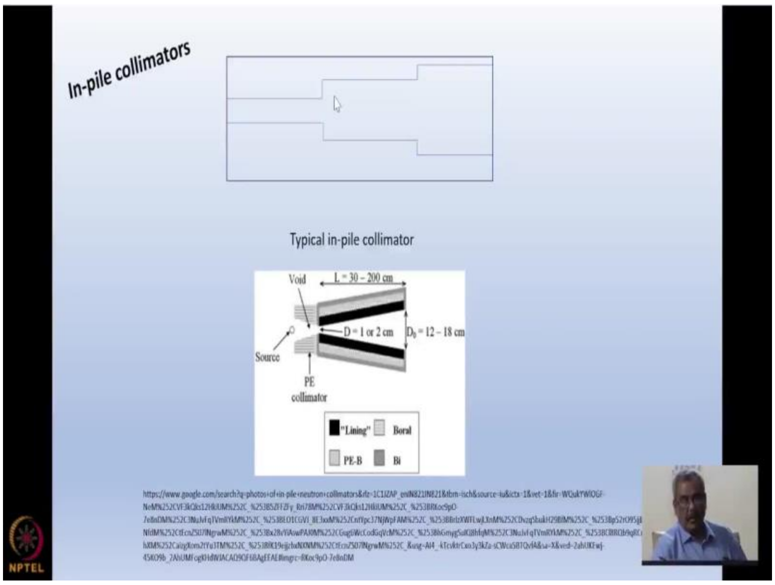

The in-pile collimator looks somewhat like as I showed you in the sketch. Here actually, it is like a cone, you can even use a conical in-pile filter. But often we do not do use shapes like this. It is easy to make cylindrical objects and the in-pile collimator may look as I show you here.

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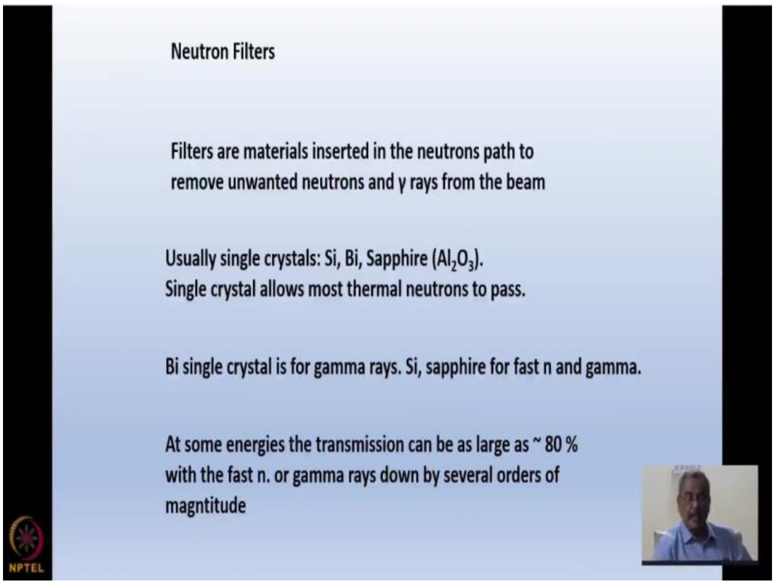

And often neutron filters are inside the beam line. Filter materials are something which will remove gamma rays from the neutron path, because gamma rays are extremely harmful for human health, and we need to cut them down to an allowable level before we start even tailoring the beam. So, we can use gamma ray absorbers. But at the same time these absorbers should be such that they allow the desirable neutrons to pass through. So how do we have this dual nature which means it will allow me to take out the thermal neutron at the same time absorb the gamma rays. We use single crystals of silicon, bismuth or even sapphire.

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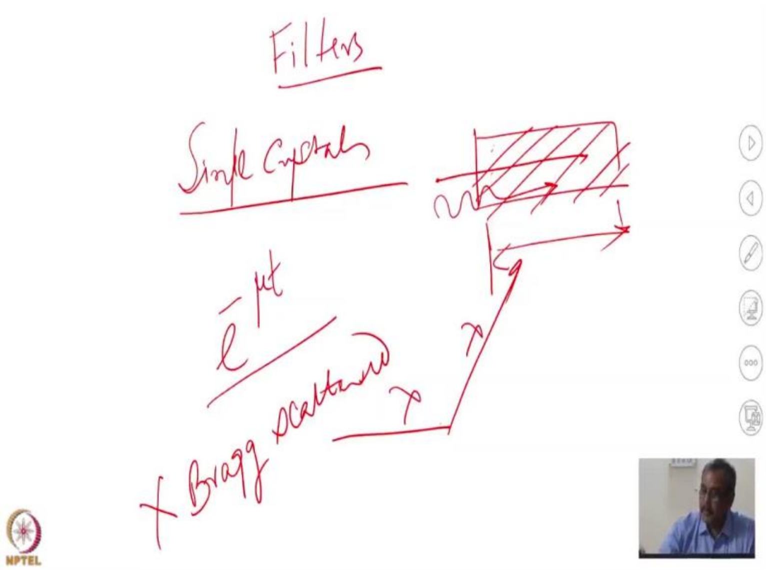

Single crystals are used because if I put a filter in the beam path, there is neutron which is trying to pass through and there is gamma ray which is going to pass through. Now, if the linear absorption coefficient isμ, for gamma I can write transmission as $e^{-\mu t}$ where t is the thickness. that is apart from the something known as built up factor because, this relation is true for pinhole geometry and this is not a pinhole geometry. Now, in case of single crystals, the neutron beam possibly has some λ will be Bragg-scattered out by this filter, but others will not get Bragg-scattered and will pass through.

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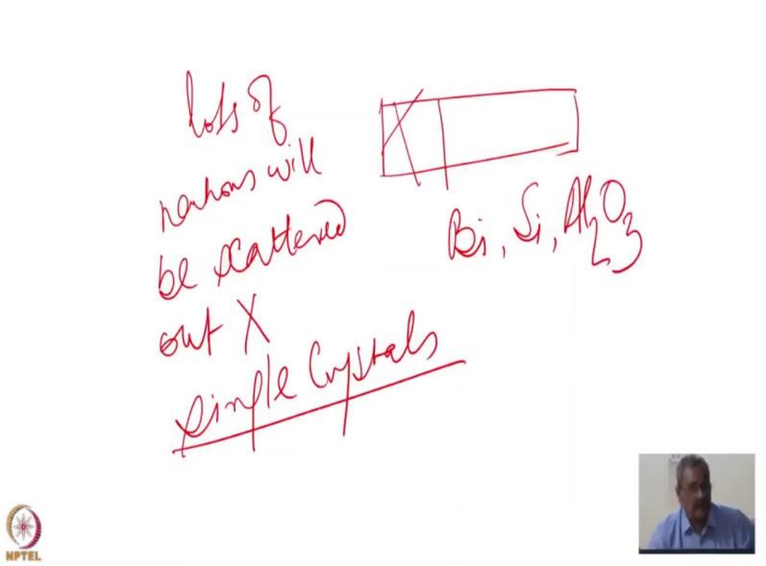

However, if we have polycrystalline material instead of single crystal then planes will be oriented in random directions in the powder. That means, we have all possible orientations in the beam path and lots of neutrons will be scattered out. This is undesirable. That is why mostly we use single crystal filters to stop gamma rays and we know high *Z* materials are desirable. Hence, we can use bismuth single crystals, we can use silicon single crystals, we can also use alumina for fast neutrons.

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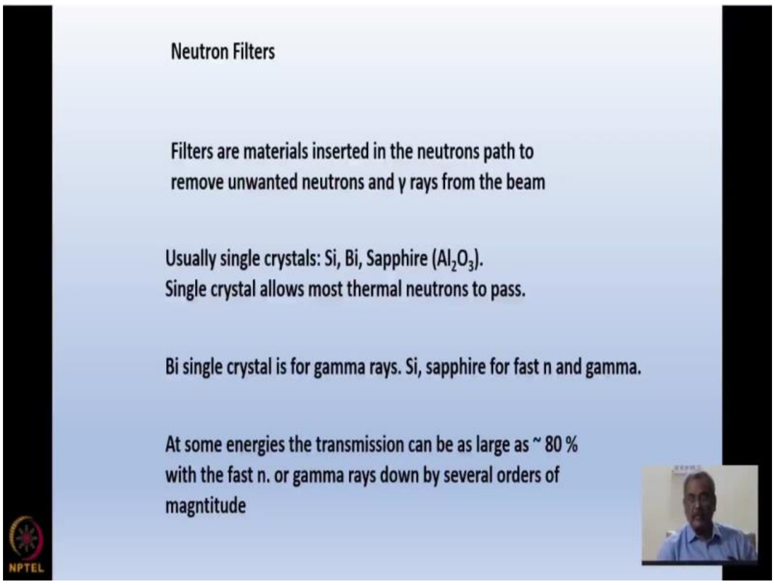

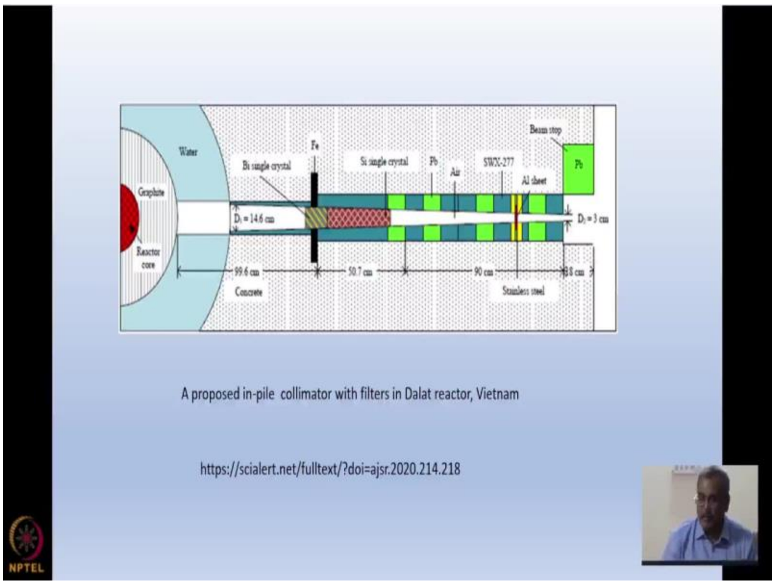

I can tell you that in some energies, the transmissions that have been measured can be as good as 80 percent with the fast neutron and gamma rays down by several orders of magnitude. So, the fast neutrons and gamma rays will be cut down and 80 percent of the thermal neutrons will pass through. We will have a rather clean beam after the filter.

Here, I just show you some of the things which are proposed (worldwide). This is a proposed beamline in Dalat reactor, Vietnam. Here they have talked about a silicon single crystal filter in their beam path. This is an imaging beam path.

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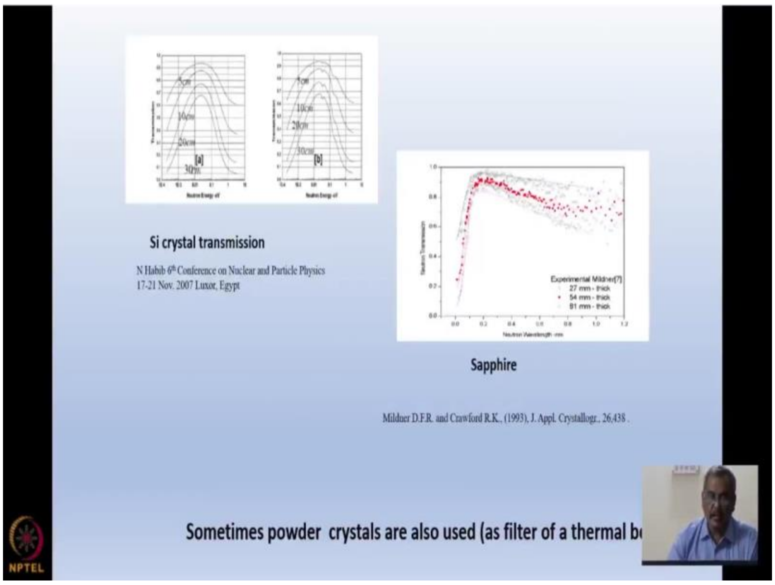

I will just show you the transmission data. These are all published ones. You can see, that especially for silicon single crystal for various thicknesses, that for some energies at the center of this plot the transmission is as large as almost 70 to 80 %. Similarly for sapphire you can see the transmission for longer wavelength neutron is large, almost 80 percent. But for short wavelength neutrons it is very low. So, sapphire can cut down the fast neutrons, at the same time it can allow the thermal neutrons preferably to pass through and they are routinely used as filters in neutron beam experiments.

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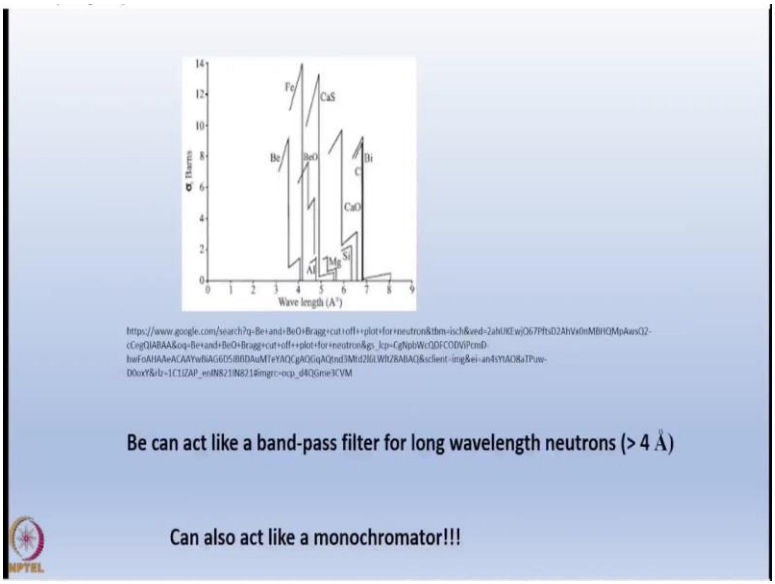

Sometimes, we can also use the same property of Bragg scattering for some of the powder crystals, powder crystals comprised many small crystallites. I am just showing you the schematic plot. You can see that the cross section drastically falls beyond say 4 Å for Be and below that there is a very large scattering cross section. Basically, it goes through Bragg scattering. What I mean to say is that when we use beryllium powder, then we have all possible orientations of planes around the beam. So, lots of lambda (neutron wavelength) will be thrown out because of Bragg scattering. Bragg scattering is very strong. From Bragg relation for the first order of diffraction, $\sin\theta = \frac{\lambda}{2d}$, we know that when λ becomes larger than the largest 2d in the system they do not get scattered anymore because then $\sin\theta$ needs to become greater than 1 which is not allowed. So, you do not have these wavelengths will not be cut off by this powder and we can use the filtered beam for use in experiments if the experiment demand long wavelength neutron.

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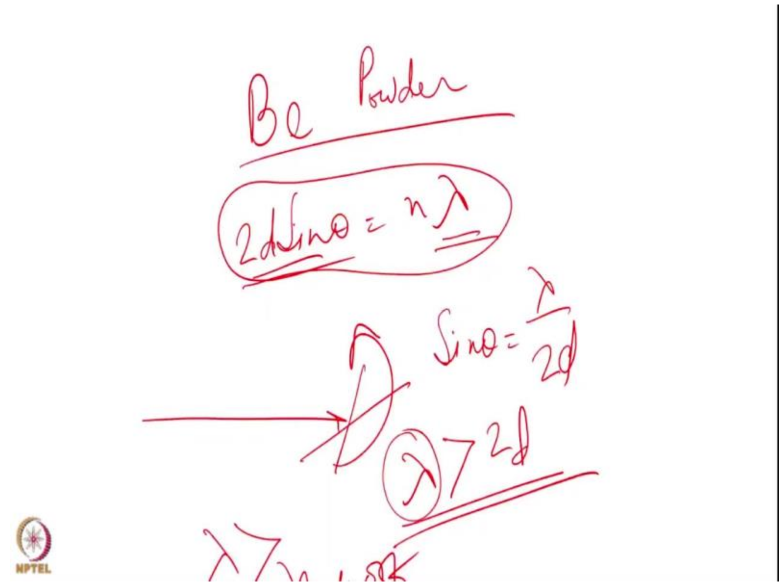

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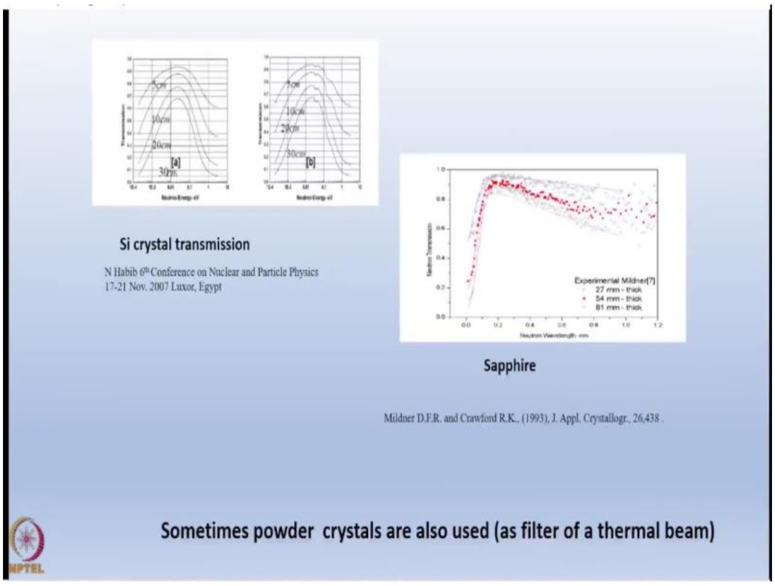

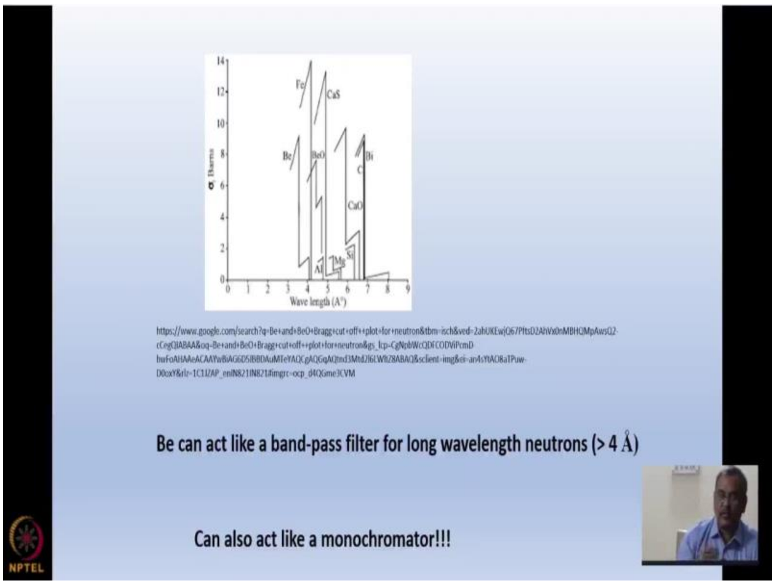

Let me consolidate by saying that we normally use single crystals to filter out gamma rays and fast neutrons from thermal neutrons with high Z single crystal. But sometimes if we want to cut down the thermal neutrons and enhance the cold neutrons for some experiments, we can also use beryllium as a filter. Similarly, some people have also measured the iron cutoff, the cutoff wavelength increases slightly in case of iron.

Likewise, if you want to use some wavelength which is greater than 7 Å and more, you can use a powder Bismuth filter, but you must remember that in the Maxwellian that is coming from the reactor, neutrons of longer wavelengths are fewer. Hence, before we use these kinds of filters, it is desirable to have a cold neutron source in place in a reactor and then in that beam path, we can use a filter. I will use an example later, where a beryllium oxide filter was used and a pseudo monochromatic beam was used for small angle neutron scattering in Dhruva.

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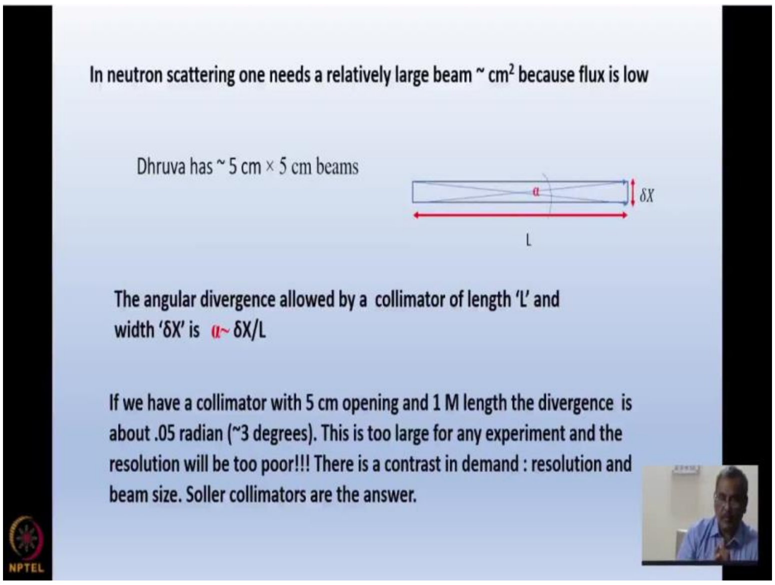

Now, question of collimation of the beam. In neutron scattering we need a relatively large beam of typical 5 cm x 5 cm. But, in such a case beam divergence will be large and divergence for a collimator is given by the simple geometrical value of $\frac{\delta x}{L}$ where δx and L are the collimator's width and the length.

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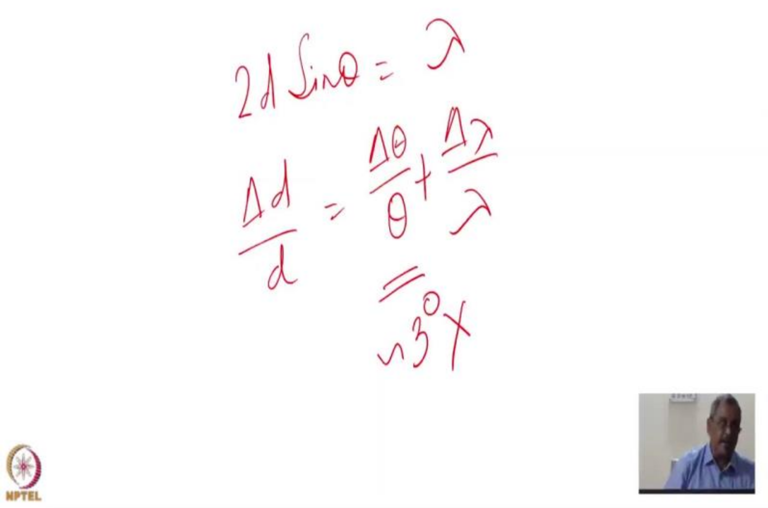

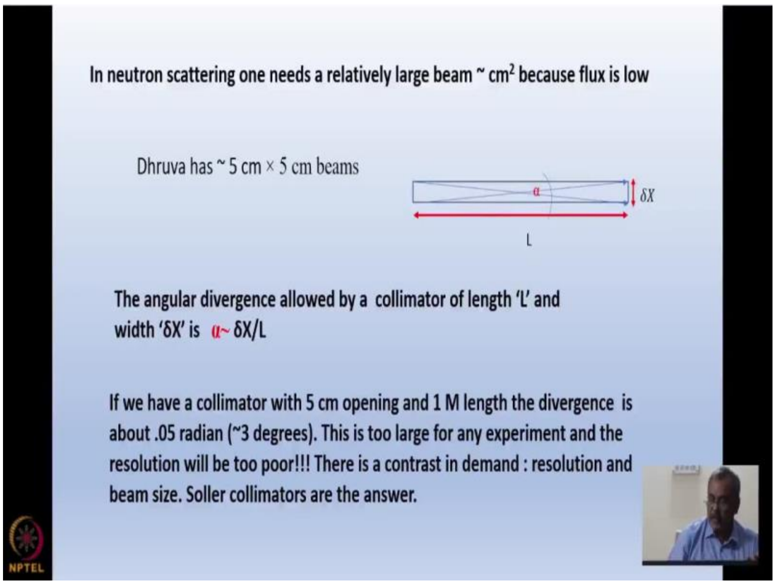

Now, if you have a collimator of 1 m length with 5 cm opening then the divergence is about 3°. This is too large for any experiment as the resolution will be poor. For example, for a diffraction experiment the resolution is given by,

$$\frac{\Delta d}{d} = \frac{\Delta\theta}{\theta} + \frac{\Delta\lambda}{\lambda}$$

Then if $\frac{\Delta\theta}{\theta}$ is 3°, it is of no use for a diffraction experiment. So, we have a competing interest. We need a large beam, but we need a smaller divergence. This is what is done by a soller collimator. It makes a compromise between resolution and beam size. How?

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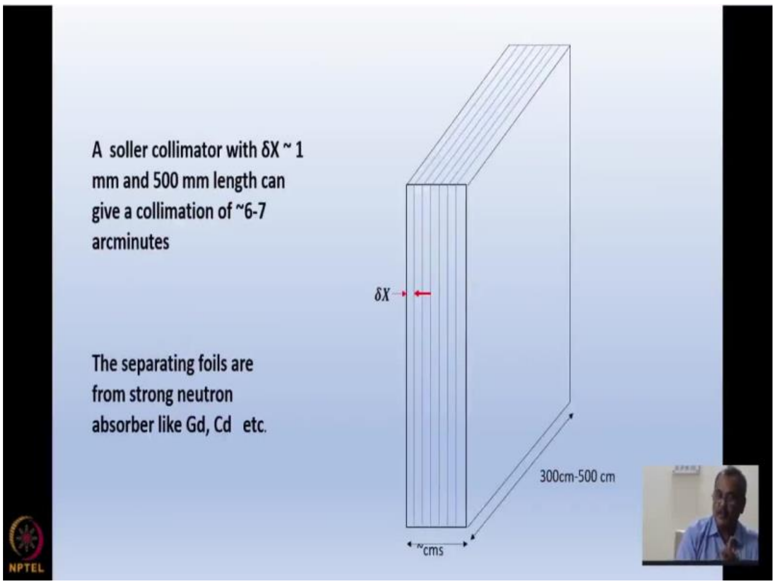

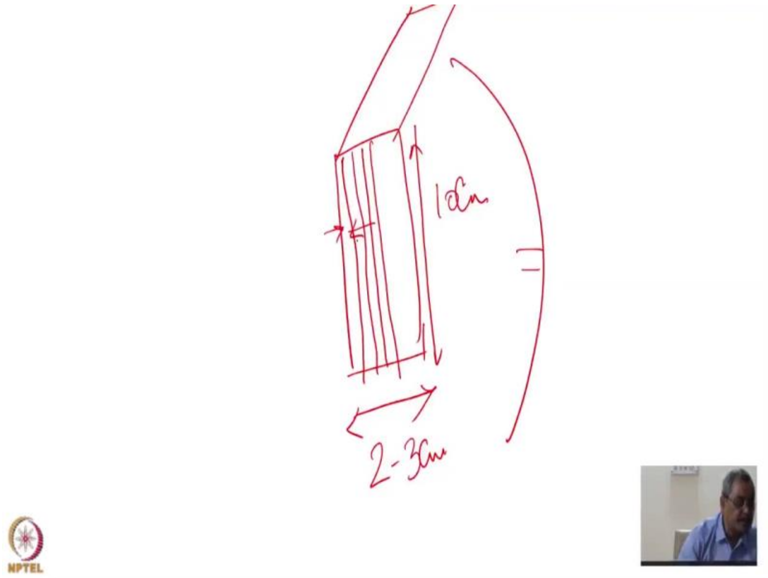

This is the typical design of a soller collimator. A soller collimator has got a rectangular cross section, usually the neutron beams are always rectangular in our experiments. If it is a horizontal geometry that I am using for scattering experiment, then the resolution is dictated by the resolution in the horizontal plane and we can play in the vertical plane as we do not have any resolution requirements in the vertical plan.

Soller collimator has a rectangular cross section and interspersed with a strong neutron absorbing material. So, if the one drawn here is the collimator, then this size is the desirable width say 2 to 3 cm and height may be of the order of 10 cm. But I can intersperse this thing with narrow slits. The beam size is dictated by the total width and the height of the collimator and the collimation is given by δX, which I have defined here as the distance between two of such absorbing materials. These absorbing materials run all throughout the length of the collimator. The separating foils are usually made from gadolinium or cadmium, and we have to take lots of pain to keep them straight so that the beam path does not get closed in the length of the collimator, which is typically 300-500 cm long.

A soller collimator with a δX = 1 mm and 500 mm length gives me a collimation of 6 to 7 arc minutes. 6 to 7 arc minutes of divergence. It is very much commensurate with a $\frac{\Delta\lambda}{\lambda}$ of few percent in a mosaic crystal and that is the best situation for a diffraction experiment.

I explained to you that a soller collimator actually makes gain by reducing the beam size width wise and at the same time allows the beam to be large. So, this is a gain-gain situation for the neutron scattering experiment and soller collimators are used in almost all beam paths where you are using a monochromatic beam.

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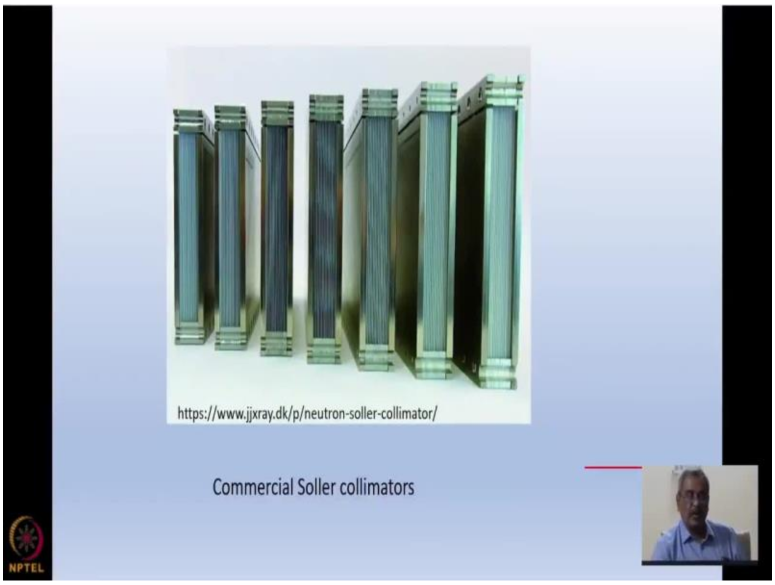

I am just showing you some photographs of this soller collimators of this company JJXRAY and you can see this is how they look like. This soller collimator is routinely used in the neutron beam path, they come after the monochromator drum and before the sample and this can reduce the angular divergence of the beam to few arcminutes at the same time provide a large beam for use in our experiment.