Inspection and Quality Control In Manufacturing
Prof. Kaushik Pal
Department of Mechanical and Industrial Engineering
Indian Institute of Technology – Roorkee

Lecture – 15
Advanced Nondestructive Testing Techniques
NDT Standards, Safety in NDT

Hello my friends we are going to start new chapter on advancing in non-destructive testing techniques NDT standards and the safety in non-destructive testing.

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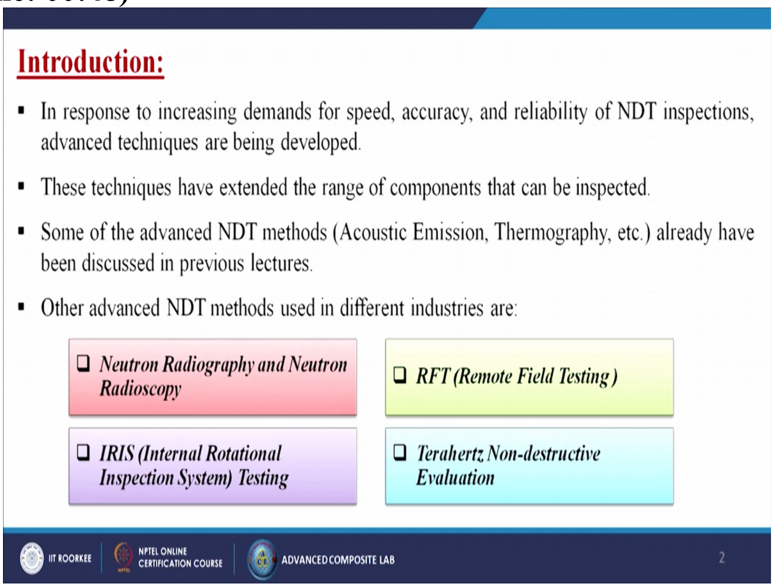

So, first let us start why we are doing these NDT testing's so generally increasing demands for speed accuracy and reliability and also the customer satisfactions in increasing tremendously for which we need to do the NDT inspections. Advanced techniques generally first and foremost I can tell you that scientist or maybe researchers are preparing the materials day by day new materials they are preparing.

So, by capturing the defects for those new materials. Of course our technology by which we are measuring these defects or may be any kind of problems inside the materials that needs to be also modified so we are just moving from the normal non-destructive testing to the advanced non-destructive testing zone. These techniques have extended the range of components that can be inspected.

Some of the advanced NDT methods like acoustic emission, like acoustic emission and thermography etcetera I already have been discussed in previous lecture that already we have discussed. Now in this particular topic we are going to discuss about some kind of advanced techniques. Other advanced NDT methods used in different industries are like Neutron radiography and neutron radioscopy, RFT remote field testing, IRIS internal rotational inspection system testing and the Terahertz non-destructive evaluation.

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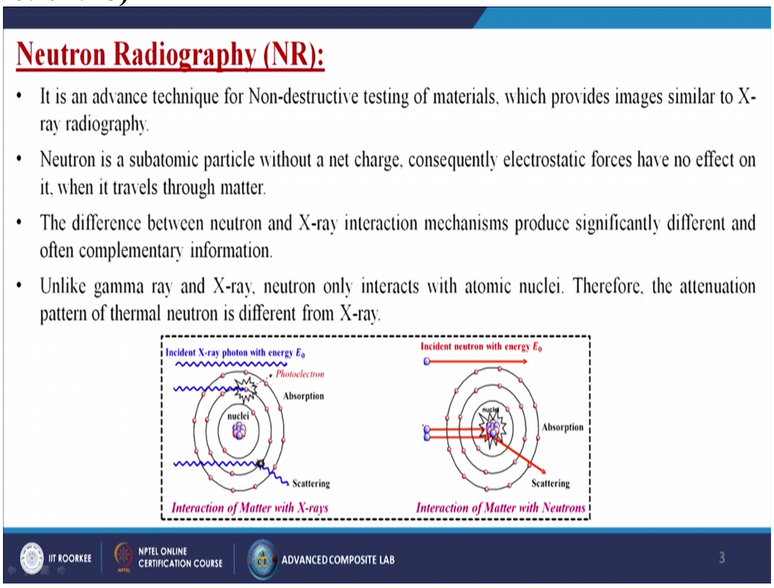

So, now what is Neutron radiography it is an advanced technique for non-destructive testing of materials which provides image similar to x-ray radiography. Neutron or maybe the actual atomic level we are talking about so it is sub particles without a net charge consequently electrostatic force have no effect on it when it travels through the matter. The difference between Neutron and extra interaction mechanism produced significantly different and often complementary information.

So, by normal x-ray we are getting some data then just we are going to narrow down our inspections and we are going to see the exact locations or maybe exact types of defects then only we are going to do this kind of techniques. Unlike gamma-ray and extra Neutron only interacts with atomic nuclei therefore the attenuation pattern of thermal Neutron is different from x-ray.

So, here when we are talking about the interaction of matter with x-rays so like this way we are having that nuclei and then the x-ray photon with energy is coming and then it is hitting our atoms and then the photo electron radiation is coming from the material itself but when we are talking about the interaction of the matter with neutrons you can see that neutrons is not hitting the atoms it is directly hitting the nuclei of that particular material.

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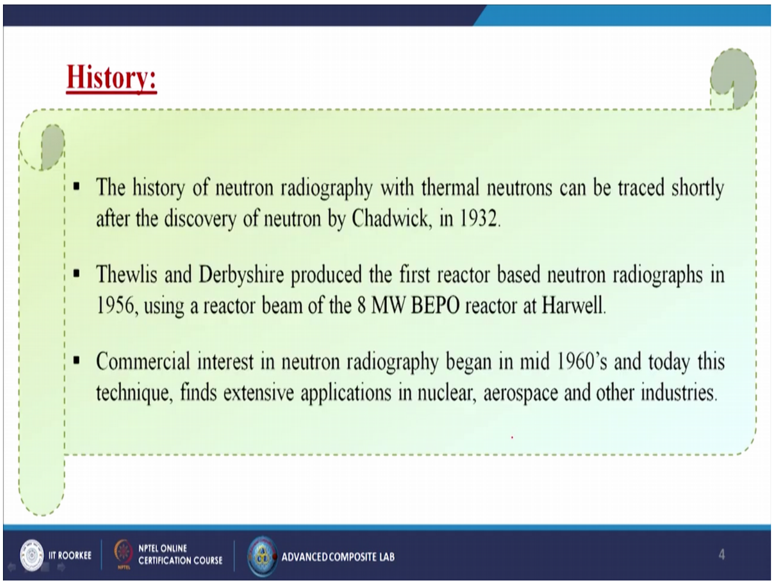

Now what is the history behind it the history of Neutron radiography with thermal neutrons can be traced shortly after the discovery of neutron by Chadwick in the year of 1932. Thewlis and Derbyshire produced the first reactor based Neutron radiographs in the year of 1956 using a reactor beam of the 8 megawatt BEPO reactor at Harwell. Commercial interest in Neutron radiography began in mid of 1960s and today these techniques finds extensive applications in nuclear aerospace and other industries.

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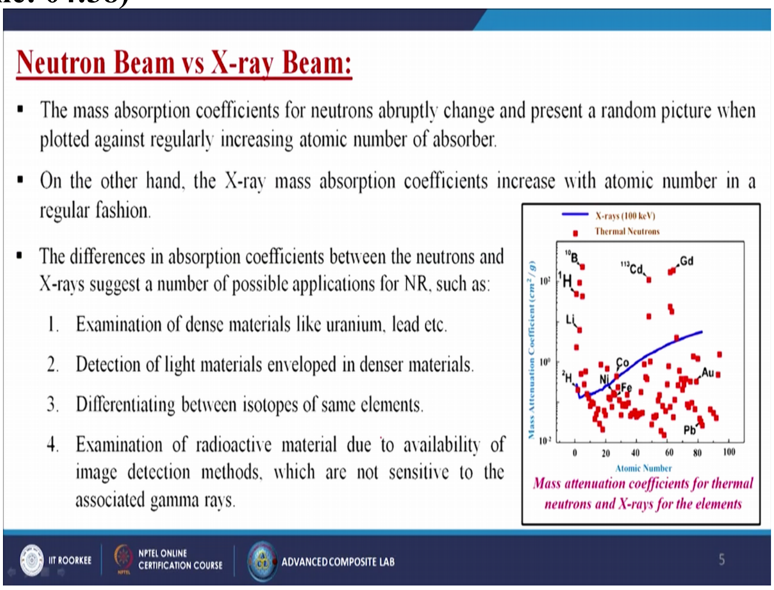

What is the neutron beam versus X-ray beam what is the difference the mass absorption coefficients of neutrons abruptly changed and present a random when plotted against regularly increasing atomic number of absorb or absorb is nothing but the material. On the other hand the X-ray mass absorption coefficients increase with the atomic number in a regular fashion.

The difference in absorption coefficients between the neutrons and the X-rays suggests a number of possible applications for Neutron beam resonance such as examination of dense materials like uranium lead etcetera. Detection of light materials enveloped in denser materials, differentiating between isotopes of same elements, examination of radioactive material due to availability of image detection methods which are not sensitive to the associated gamma rays.

So, in this particular case you can understand that the marts attenuation coefficients for thermal neutrons and X-rays for the elements itself. So, now X-rays the blue in line and now the thermal neutrons you can see that red dots over here. So, this side the atomic number is increasing and this side the mass attenuation coefficient is increasing. Now we can see that very easily it is detecting the boron, cadmium then cobalt nickel, iron, gold, lead, lithium this kind of materials in a very precise manner it is detecting those materials.

Now Neutron radiography versus x-ray radiography means what extra results or may be the interpretations we are getting from that particular image.

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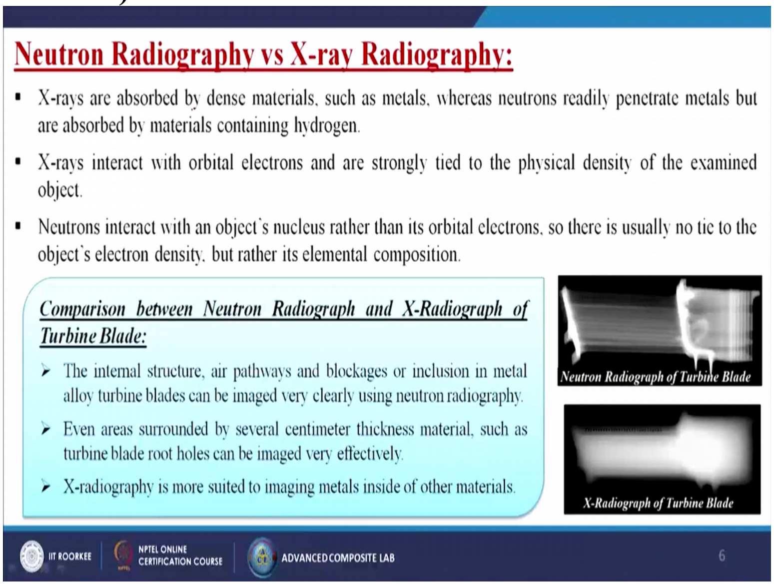

X-rays are absorbed by dense materials such as metals whereas neutrons readily penetrate metals but are absorbed by materials containing hydrogen. So, actually it is just hitting into the molecular level of that particular material. X-rays interact with orbital electrons and are strongly tied to the physical density of the examined object. Neutrons interact with an object's nucleus rather than its orbital electrons so there is usually no tie to the object's electron density but rather its elemental composition.

Comparison between Neutron radiography and X radiograph of turbine blade, the internal structure air pathways and blockages or inclusions in metal alloy turbine blades can be imaged very clearly using Neutron radiography. Even area surrounded by several centimeter thickness material such as turbine blade root holes can be imaged very effectively. X-radiography is more suited to imaging metals inside of other materials.

Now you can see the difference between the images so how it is clear we can easily see all the holes over there and as we know the holes diameter are too small. But in this case you see we are getting some kind of blurred kind of images from the x-ray or maybe the x-radiographs.

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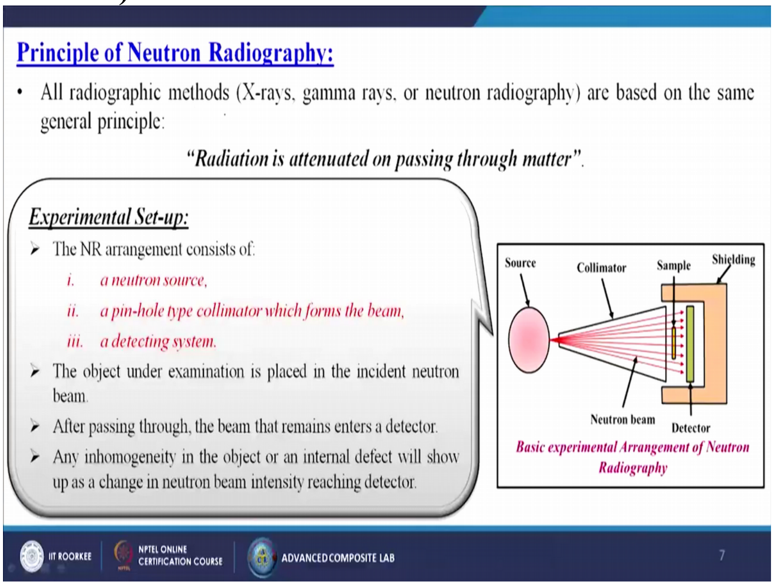

Now what are the principles of Neutron radiography all radiographic methods like x-rays gamma rays or maybe the Neutron radiography are based on the same general principle. Radiation is attenuated on passing through matter this is the main principle of this kind of techniques. Experimental setup the inner arrangement consists of a neutron source so this is the source. A pinhole type collimator which forms the beam so this is the collimator and detecting systems so just this is our detector over there.

The object under examination is placed in the incident Neutron beam after passing through the beam that remains enters a detector any in homogeneity in the object or an internal defect will show up as a change in Neutron beam intensity reaching detector so from there just we are getting our data.

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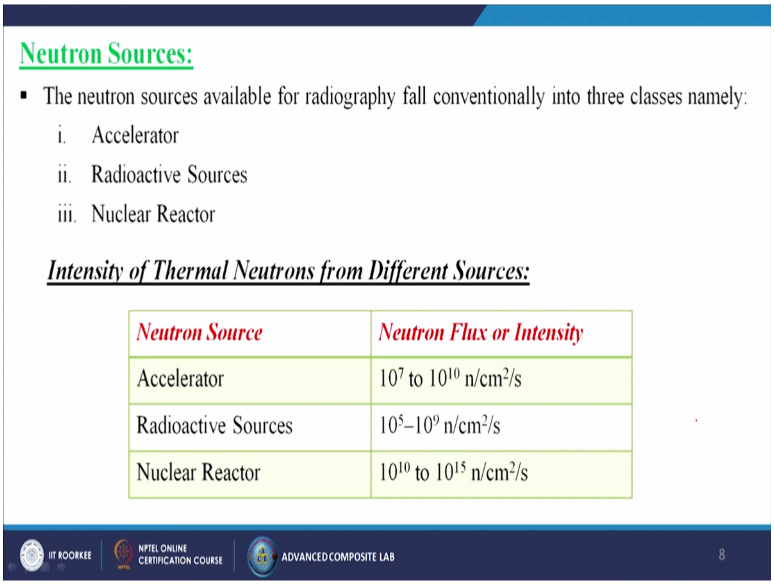

What are the Neutron sources so generally accelerator, radioactive sources or maybe the nuclear reactor. Now if we talk about the intensity of thermal neutrons from different sources so neutron source like accelerator it is 10 to the power 7 to 10 to the power 10 neutron per centimeter square per seconds. If we talk about the radioactive sources it is 10 to the power 5 to 10 to the power 9 neutron per centimeter square per second.

If we talk about the nuclear reactor it is 10 to the power 10 to 10 to the power 15 neutron per centimeter square per second.

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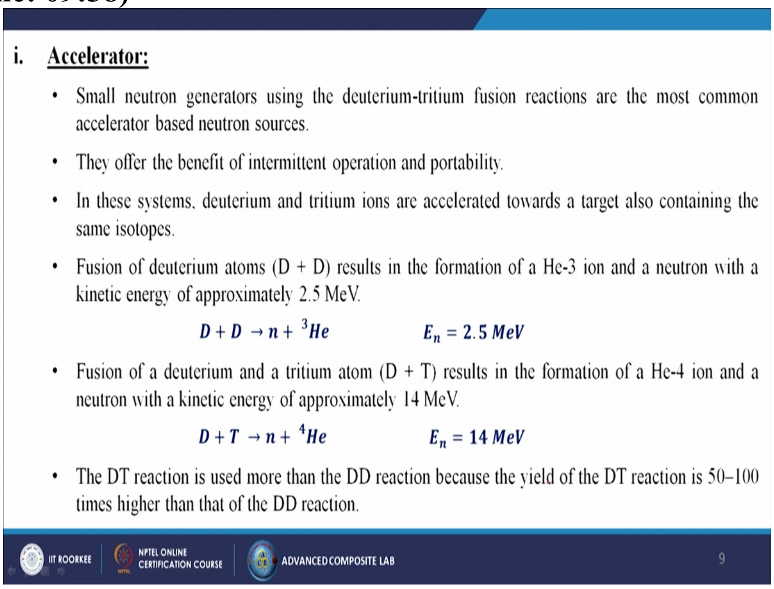

Then what is accelerator small neutron generators using the deuterium-tritium fusion reactions are the most common accelerator based neutron sources. They offer the benefit of intermediate operations and portability. In these systems joy tritium and tritium ions are accelerated towards a target also containing the same isotopes. Fusion of deuterium atoms that is D + D results in the formation of a helium-3 ion and a neutron with a kinetic energy of approximately 2.5 mega electron volt.

So, in this particular case when the two deuterium atoms are colliding each other then what is happening and what is the kinetic energy we are going to achieve. Then fusion of a deuterium and a tritium atom that is D + T results in the formation of a helium 4 ion and a neutron with a kinetic energy of approximately 14 mega electron volt so you can understand. The DT reaction is used more than the DD reactions because the yield of the DT reaction is 5200 times higher than that of the DD reactions of course.

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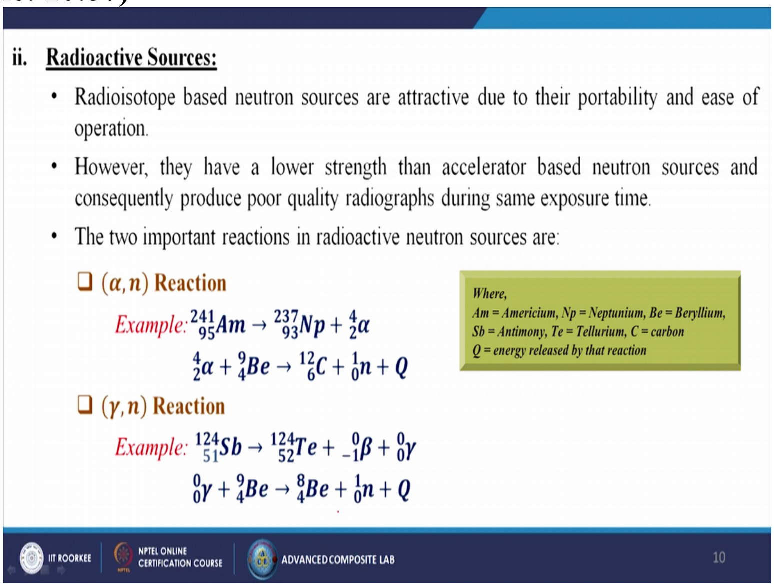

Next when you are talking about the radioactive sources radioisotope based Neutron sources are attractive due to their portability and ease of operation. However they have a lower strength than accelerator based Neutron sources and consequently produce poor quality radiographs during the same exposure time, exposure time means how much time you are keeping that incident beam on to your sample.

So, the two important reactions in radioactive Neutron sources are say suppose if I give the examples of the alpha and neutron reactions. So, in this particular case you can see that from americium we are making the neptunium and then 4/2 alpha that means the mass number and an atomic number of alpha. This is very important and then that 4/2 alpha we are adding with the beryllium and then after that it is forming the carbon and high heat energy release is taking place from that particular reactions.

Same thing when we are talking about the gamma n reactions we are having the antimony from antimony we are making the tellurium. And the beta and the gamma and then these gamma we need for the beryllium case and then after that we can get that we are getting a high energy released by this particular reaction.

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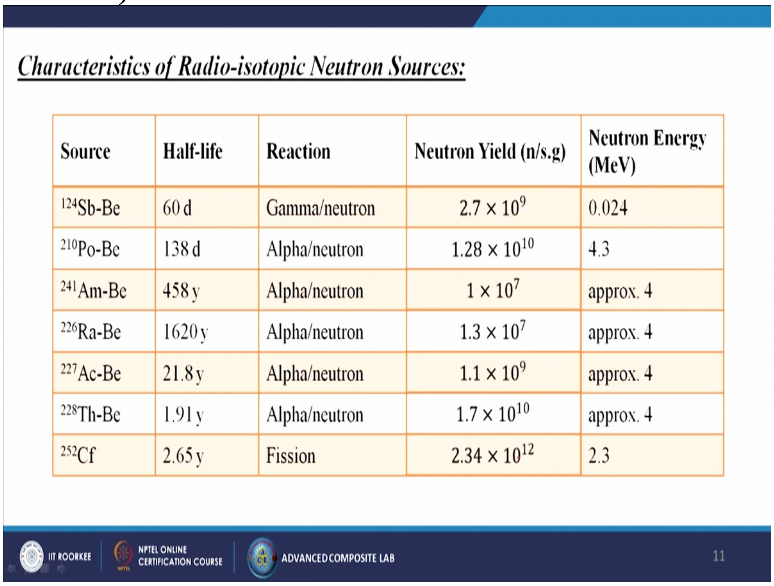

Characteristics of Radio-isotopic Neutron Sources:

Source	Half-life	Reaction	Neutron Yield (n/s.g)	Neutron Energy (MeV)
^{124}Sb-Be	60 d	Gamma/neutron	2.7×10^{9}	0.024
^{210}Po-Be	138 d	Alpha/neutron	1.28×10^{10}	4.3
^{241}Am-Be	458 y	Alpha/neutron	1×10^{7}	approx. 4
^{226}Ra-Be	1620 y	Alpha/neutron	1.3×10^{7}	approx. 4
^{227}Ac-Be	21.8 y	Alpha/neutron	1.1×10^{9}	approx. 4
^{228}Th-Be	1.91 y	Alpha/neutron	1.7×10^{10}	approx. 4
^{252}Cf	2.65 y	Fission	2.34×10^{12}	2.3

So, now we are going to talk about the characteristics of different types of radio isotopic Neutron sources like we are having that antimony beryllium so half-life is the 60 days reaction is the gamma Neutron reactions and then if we are talking about the neutron yield that is Neutron per second per gram then 2.7 * 10 to the power 9. When you are talking about the neutron energy in mega electron volt it is 0.024. so, now like this way we are having one chart over there like polonium/beryllium like americium/beryllium like radium/beryllium right actinium/barium like thorium/beryllium and last one is the californium.

So, californium you can see the half-life is too high it is 2.65 years reaction is the fission and neutron yield is 2.34* 10 to the power 12 and neutron energy is 2.3 mega electron volt.

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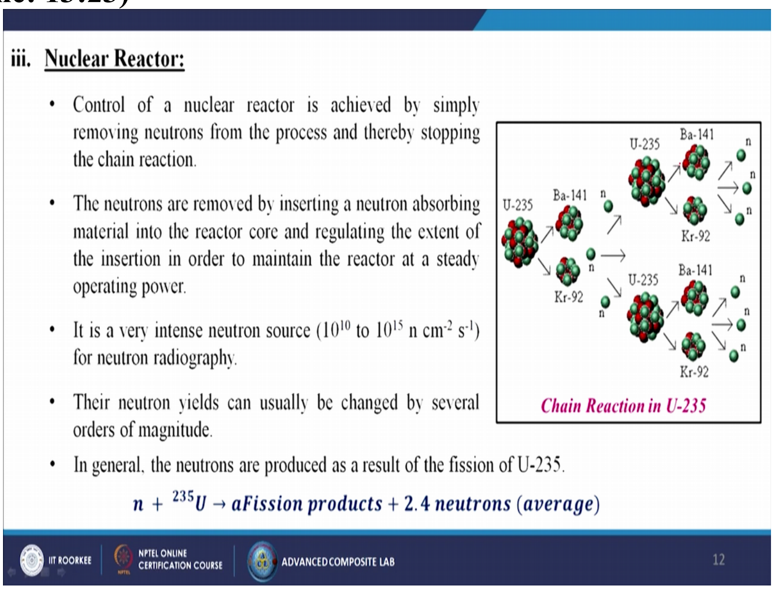

Now come to the nuclear reactor the control of a nuclear reactor is achieved by simply removing neutrons from the process and thereby stopping the chain reaction. The neutrons are removed by inserting a neutron absorbing material into the reactor core and regulating the extent of the insertion in order to maintain the reactor at a steady operating power. It is a very intense neutron source like 10 to the power 10 to 10 to the power 15 neutron per centimeter square per second form Neutron radiography.

There Neutron yields can usually be changed by several orders of magnitude in general the neutrons are produced as a result of the fission of uranium-235. So, generally this is the fission products and it is generating 2.4 neutrons in average.

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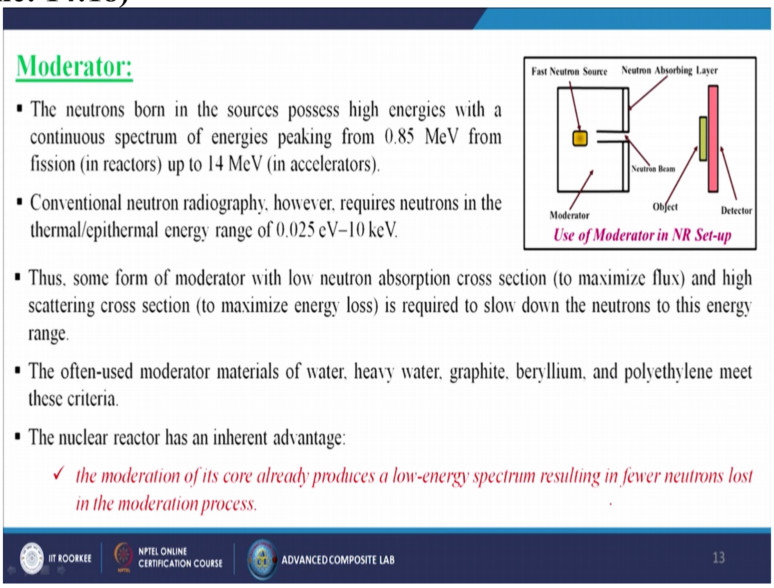

Now come to the moderator the neutrons born in the source possess high energies with a continuous spectrum of energy speaking from 0.85 mega electron volt from fission in reactors up to 14 mega electron volt in accelerators. Conventional Neutron radiography however requires neutrons in the thermal or maybe the AP thermal energy range of 0.025, electron volt to 10 kilo electron volt. The some form of moderator with low Neutron absorption cross-section to maximize the flask and high scattering cross-section to maximize the energy loss is required to slow down the neutrons to this energy range.

Simple it is energizing the neutrons so that more electrons I can get or maybe that high speed of neutrons I can get or maybe sometimes it is slower down the speed or maybe the less number of neutrons it is allowing to pass. The often used moderator materials of water heavy water graphite beryllium and polyethylene meet this particular criterion. The nuclear reactor has an inherent advantage like that the moderations of its core already produce a lower energy spectrum resulting in fewer neutrons lost in the moderation process.

So, in this particular case you can see this is the moderator that means how many neutrons will go and it will heat your object so simple heat is changing that number and the speed simultaneously.

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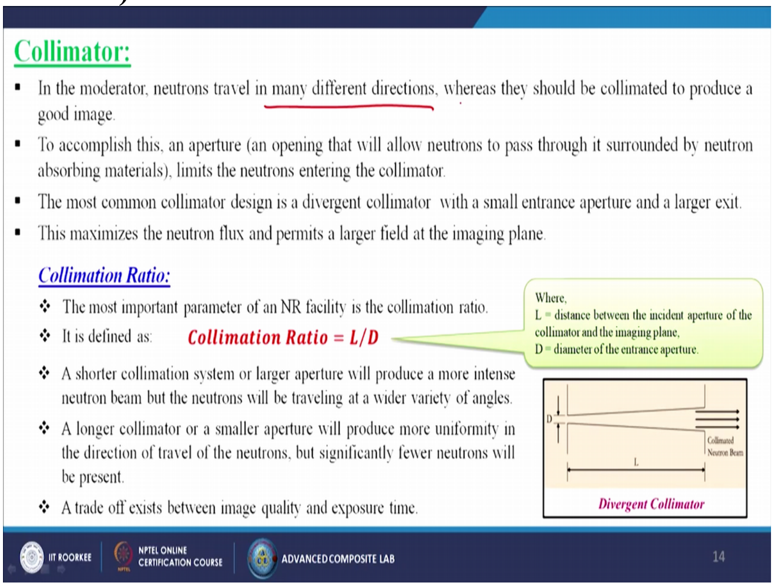

Next come to the collimator, so in the moderator neutrons travel in many different directions whereas they should be committed to produce a good image. So, neutrons can go any directions so what is the role of the collimator it will try to move all the neutrons in a particular path. It will just stop the scattering of the neutrons to accomplish this an aperture an opening that will allow neutrons to pass through it surrounded by neutron absorbing materials limits the neutrons entering the collimator.

The most common collimator design is a divergent kilometer with a small entrance aperture and a larger exist. This maximizes the neutron flux and permits a larger field at the imaging plane. Now what is the collimation ratio the most important parameter of an inner facility is the collimation ratio it is defined as that L / D where L is the distance between the incident aperture of the collimator and the imaging plane so this is L and D is the diameter of the entrance aperture so here is the D.

A shorter collimation systems or larger aperture will produce a more intense Neutron beam but the neutrons will be traveling at a wider variety of angles. A longer collimator or a smaller aperture will produce more uniformity in the direction of trouble of the neutrons but significantly fewer neutrons will be present a trade of exits between image quality and exposure time.

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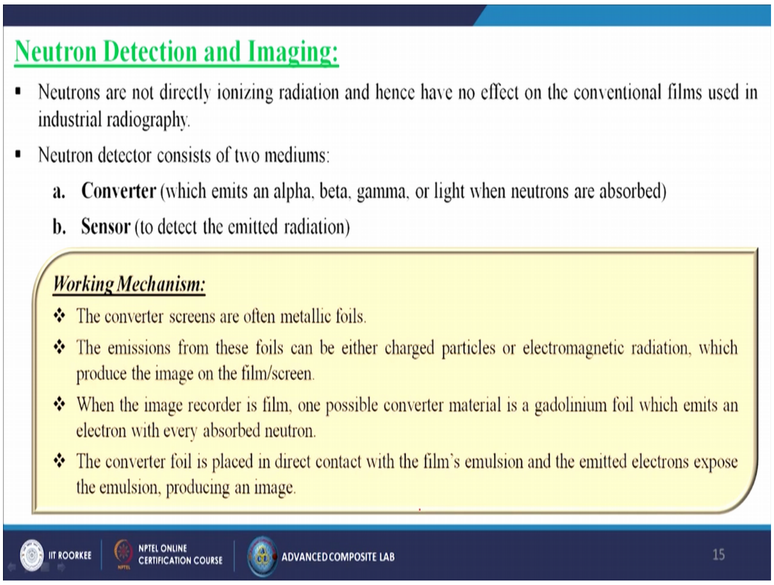

Now neutron detection and imaging neutrons are not directly ionizing radiation and hence have no effect on the conventional frames used in the industrial radiography. Neutron detector consists of two mediums like converter which emits an alpha beta gamma or light when neutrons are absorbed and the second one is the sensor to detect the emitted radiation. Working mechanisms the converter screens are often metallic foils the emissions from these false can be either charged particles or electromagnetic radiations which produce the image on the film or maybe the screen.

When the image recorder is film one possible converter material is a gadolinium foil which emits an electron with every absorbed Neutron. The converter foil is placed in direct contact with the frames emulsion and the emitted electrons expose the emulsion produce an image.

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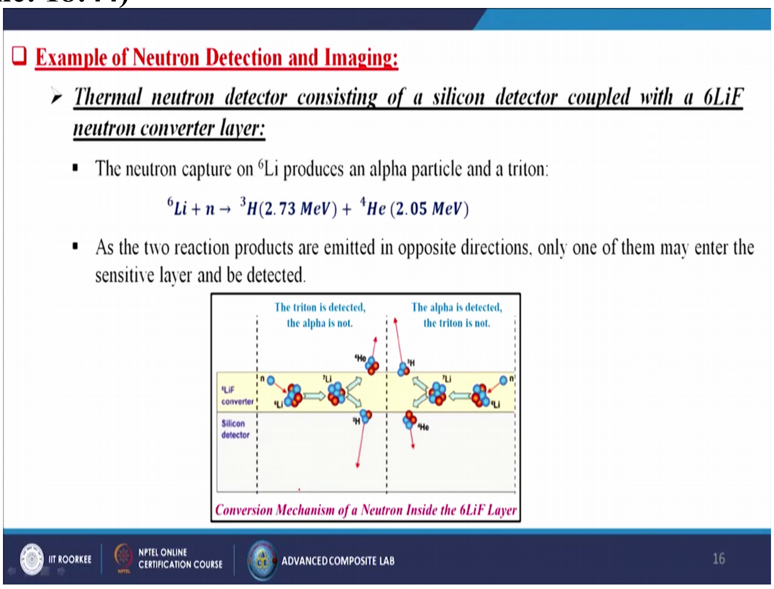

Now example of neutron detection and the imaging thermal Neutron detector consisting of a silicon detector coupled with a 6 lithium fluoride Neutron converter layer so the neutron capture on that lithium produce an alpha particle and a tritium, so lithium + n = 3 hydrogen which is generating 2.73 mega electron volt + 4 helium that is generating 2.05 mega electron volt. As the two reaction products are emitted in opposite directions only one of them may enter the sensitive layer and be detected.

So, in this particular case you can see that conversion mechanism of a neutron inside the 6 LIF layer. so, the tritium is detected the Alpha is not in this particular case the Alpha is detected the tritium is not. So, these all are the cases.

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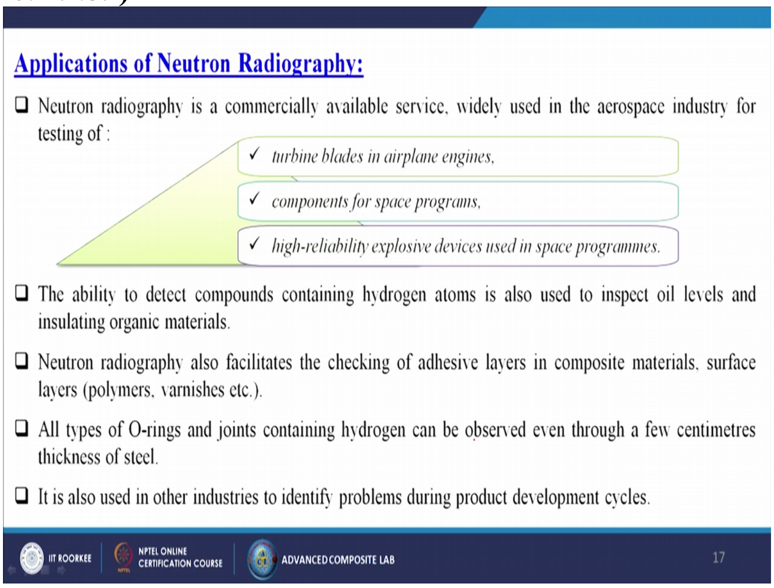

Now applications of Neutron radiography, Neutron radiography is a commercially available service widely used in the aerospace industry for testing of turbine blades in aeroplane engines. Components for space programs high, reliability explosive devices used in the space programs. The ability to detect compounds containing hydrogen atoms is also used to inspect oil levels and insulating organic materials. Neutron radiography also facilitates the checking of adhesive layers in composite materials surface layers like polymers varnishes etcetera.

All types of O-rings containing hydrogen can be observed even through a few centimeters thickness of steel and also it is used in other industries to identify problems during product development cycles.

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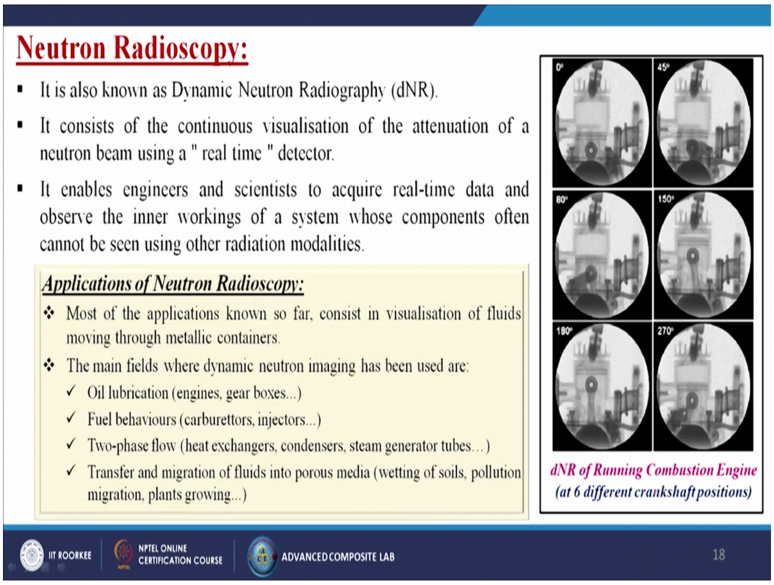

Now come to that neutron radioscopy, so it is also known as dynamic neutron radioscopy or maybe in terms or maybe in shorts generally you are calling it as a DNR. It consists of a continuous visualization of the attenuation of a neutron beam using a real-time detector. It enables engineers and scientists to echo a real-time data and observe the inner workings of a system whose components often cannot be seen using other radiation modalities.

So, inside what is happening our normal I cannot see say suppose one engine is working inside that how piston is moving so by this image we can easily get the information. Applications of neutron radioscopy most of the applications known so far consists in visualization of fluids moving through metallic containers the main fields where dynamic Neutron imaging has been used for oil lubrications for the petroleum industry like engines gearboxes fuel behaviors like carburetors injectors.

Two-phase flow like heat exchangers condenser stream generator tubes and the last one transfer and migration of fluids into porous media like wetting of soils pollution migrations plant growing etcetera.

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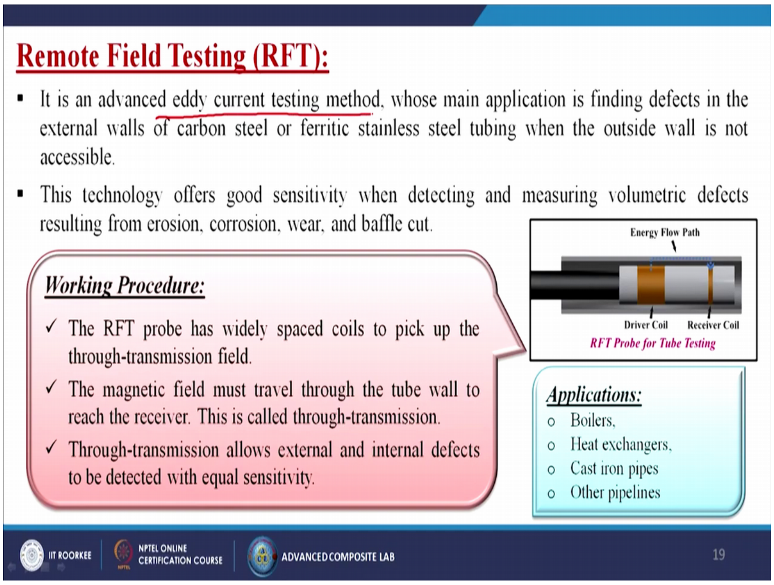

Next one is called the remote field testing or maybe in short general you are calling it as RFT. It is an advanced eddy current testing methods whose main application is finding defects in the external walls of carbon steel or maybe the faradic stainless steel tubing when the outside wall is not at all accessible to us. These technology offers good sensitivity when detecting and measuring volumetric defects resulting from erosion, corrosion, wear and the baffle cut.

So, in this particular say case you can see that RFT preferred tube testing. So, in this particular case we are having one driver coil we are having one receiver coil over there so energy flow path how the energy is flowing that the energy is flowing through this particular time. So, if there is some defects will occur so automatically the same energy will not transfer to the receiver end.

So, the working procedure the RFT probe has widely spaced coils to pick up the true transmission field. The magnetic field must trouble through the tube wall to reach the receiver this is called the through transmission. Through transmission allows external and internal defects to be detected with equal sensitivity. Applications we are using it for the boilers heat exchangers cast-iron pipes and other pipelines.

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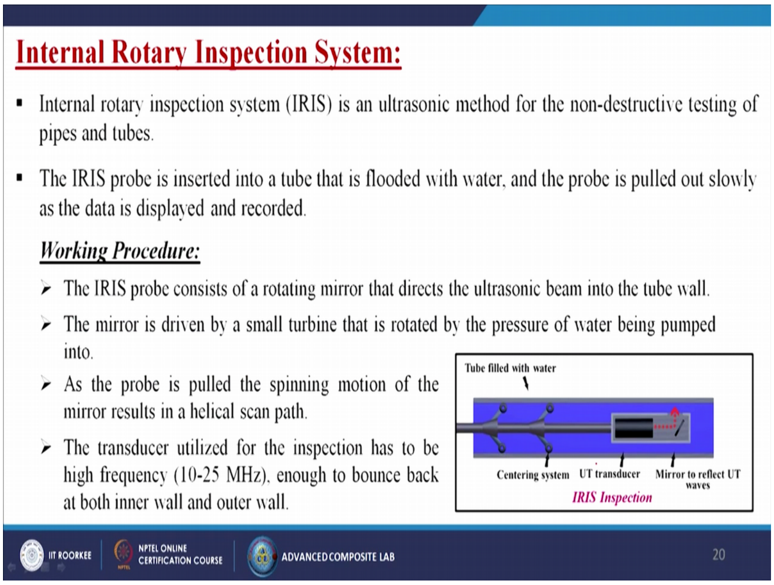

Next come to the internal rotary inspection system, so generally the internal rotary inspection systems in short general you are calling it as IRIS is an ultrasonic method for the non-destructive testing of pipes and tubes. The IRIS probe is inserted into a tube that is flooded with water and the probe is pulled out slowly as the data is displayed and recorded. You see now we are having that Center resistance.

We are having that ultrasonic transducer over there and mirror to reflect the UT waves over there. So, in this particular case just we are getting the online data from our particular products. The IRIS probe consists of a rotating mirror that directs the ultrasonic beam into the tube wall so this is the mirror over there. The mirror is driven by a small turbine that is rotated by the pressure of water being pumped into.

As the probe is pulled the spinning motion of the mirror resulting in a helical scan path so it is rotating in this particular action. So, the transducer utilized for the inspection has to be high frequency like 10 to 25 megahertz enough to bounce back at both inner wall and the outer wall.

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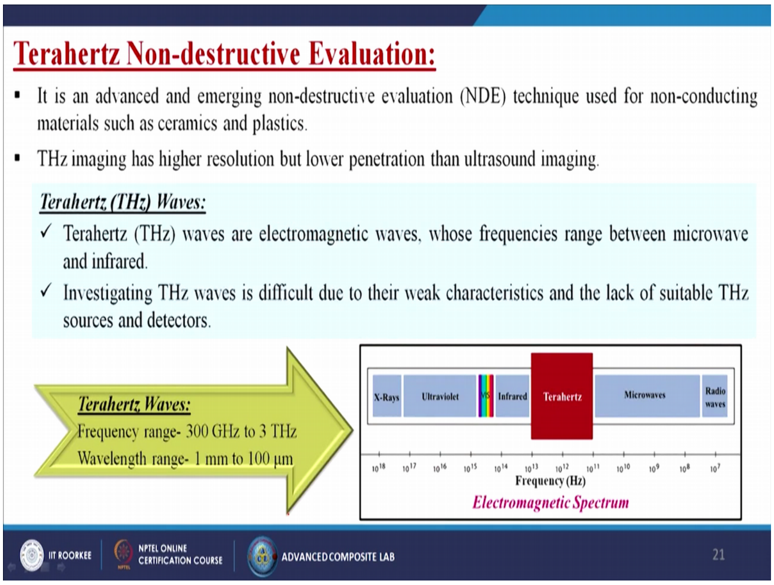

Next terahertz non-destructive evaluation it is an advanced and emerging non-destructive evaluation technique used for non conducting materials such as ceramics and plastics. Terahertz imaging has higher resolution but lower penetration then ultrasound imaging. What is terahertz waves? Terahertz waves are electromagnetic waves whose frequencies range between microwave and infrared.

Investigating Terahertz waves is difficult due to their weak characteristics and the lack of switchable terahertz sources and detectors. So, terahertz waves generally frequency ranges 300 gigahertz to 3 terahertz wavelength range is 1 millimeter to 100 micrometer. So, this is the zone actually we are talking about the terahertz that is 10 to the power 13 to 10 to the power 11.

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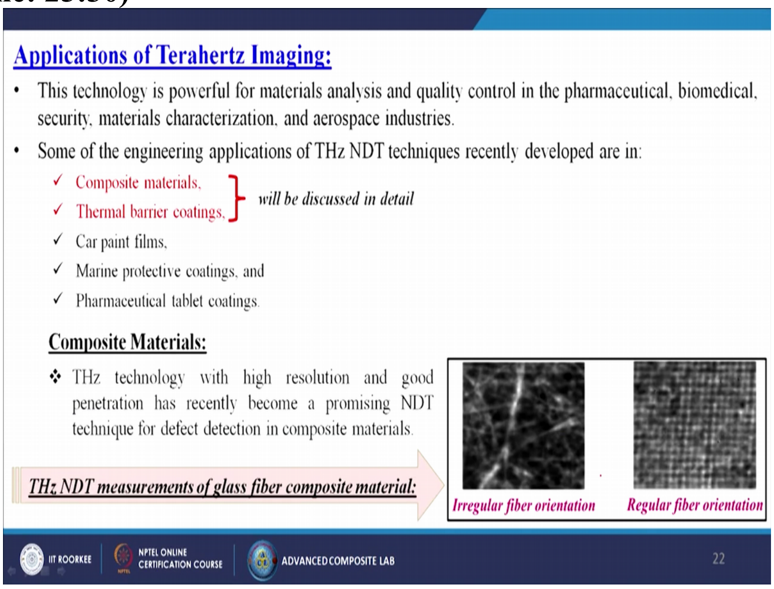

Applications of Terahertz imaging this technology is powerful for materials analysis and quality control in the pharmaceutical, biomedical, security material characterization and aerospace industries. Some of the engineering applications of terahertz NDT techniques recently developed are in for composite materials and the thermal barrier coatings, car paint films, marine protective coatings and the pharmaceutical tablet coatings.

Now let us discuss about the composite materials. So, terahertz technology with high resolution and good penetration has recently become a promising non-destructive testing techniques for defect detection in composite materials. So, here you can see the irregular fiber orientations. In this particular case we are getting the regular fiber in orientations that means inside the materials whether it is the laminated one or in the centrist one or maybe the single one so, we are getting the image that how the fiber is there inside our composite materials.

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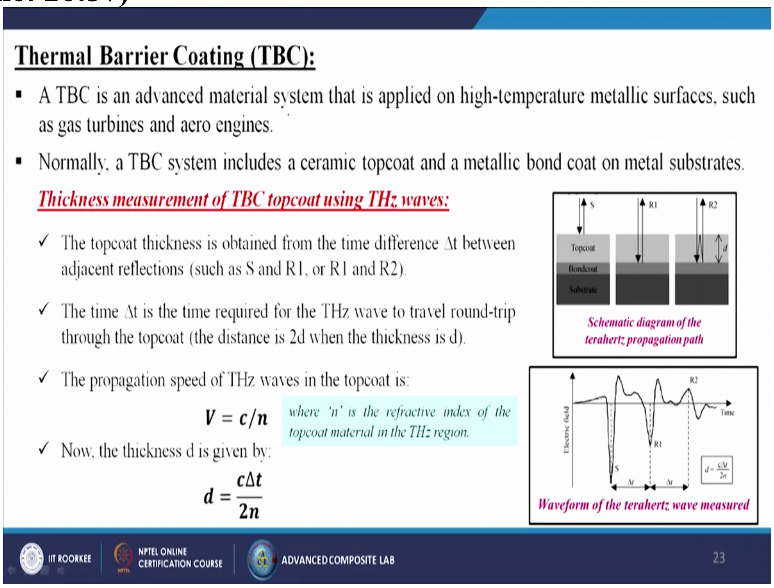

Next thermal barrier coating a TVC is an advanced material system that is applied on high temperature metallic surfaces such as gas turbines and for the aero engines. Normally a TVC system includes a ceramic topcoat and metallic bond coat on metal substrates. Thickness measurement so how much thickness means what is the thickness we are maintaining for doing the coating of our materials.

How we can measure that particular dimensions or maybe the thickness. So, the topcoat thickness is obtained from the time difference del t between the adjacent reflections such as s and R 1 or R 1 and R 2. So, here from the topcoat s and then it is coming so this is your topcoat this is your bond and this is your substrate so R 1 is from the joining of topcoat and the bond coat. The time del t is the time required for the terahertz wave to travel round-trip through the top coat the distance is 2d when the thickness is d.

The propagation speed of terahertz waves in the top coat is V = c/ n where n is the refractive index of the top coat material in the terahertz region. Now the thickness d is given by d = c del t /2n so this is the equations. So, now I can get the wave form of the terahertz measured so I am applying these particular equations over there and then I can get the whole information about the coating thickness.

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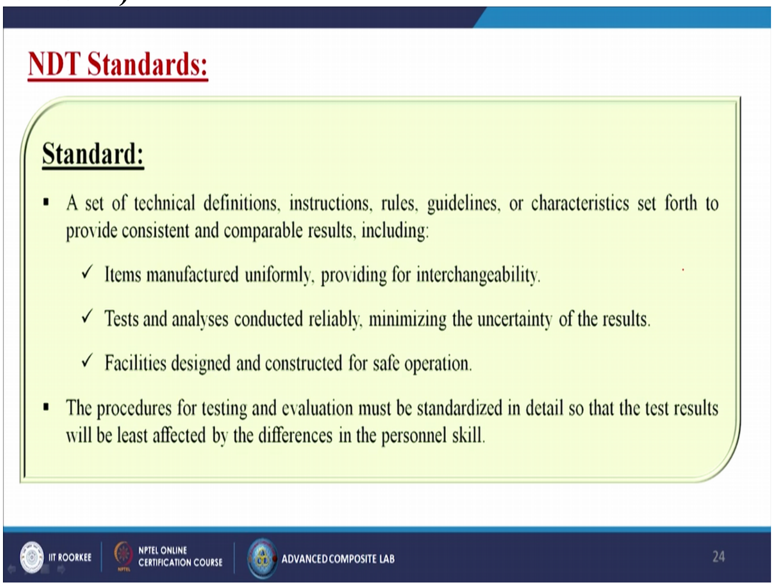

Now let us discuss about the NDT standards so what are the standards? A set of technical definitions instructions rules guidelines or characteristics set forth to provide consistent and comparable results including items manufactured in uniformly provide for interchangeability taste and analysis conducted reliably minimizing the uncertainty of the results, facilities designed and constructed for safe operation.

The procedures for testing and evaluation must be standardized in detail. So, that the test results will be least affected by the difference in the personal skill.

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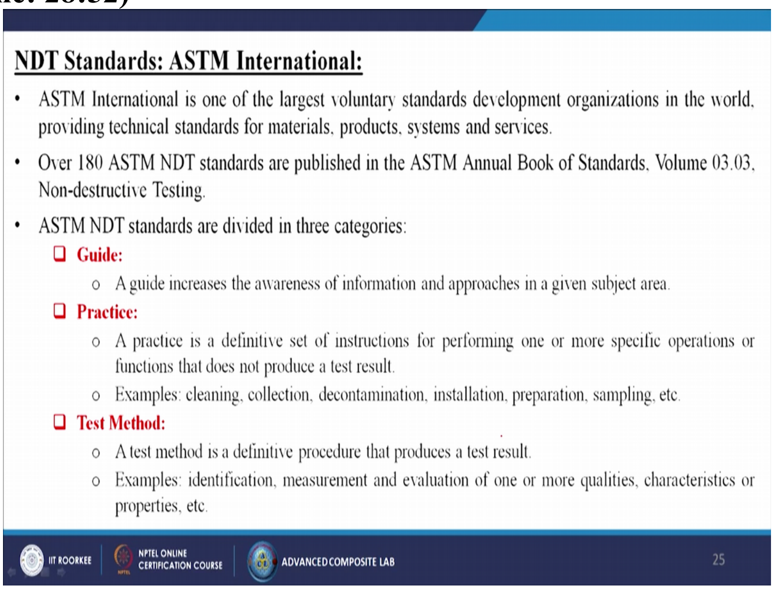

NDT standards like as per the ASTM international standards. So, generally the ASTM International is one of the largest voluntary standards development organizations in the world providing technical standards for materials, products, systems and services. Over 180 ASTM NDT standards are published in the ASTM annual book of standards volume 03.03.2014 non-destructive testing.

STM NDT standards are divided in three categories like guide a guide increase the awareness of information and approaches in a given subject area. Then practice a practice is a definitive set of instructions for performing one or more specific operations or functions that does not produce a test results and examples are cleaning, collection, decontamination, installation preparation, sampling etcetera.

And the test method a test method is a definitive procedure that produces a test results like identification and measurement evaluation of one or more qualities characteristics or properties that means actually this is first guiding us and then there these standards are helping us to choose the proper characterization techniques and how to perform. It is not that any time I can do any kind of operations no for that either we need a particular sample size or maybe the sample properties or maybe the sample cleaning and then after that we can perform these kind of tests.

So, it will give you an overall idea that how to prepare your samples in which way you can install your inspection probes over there and then how fast or maybe how slow you can move your probes and then by which you can get the best results out of that.

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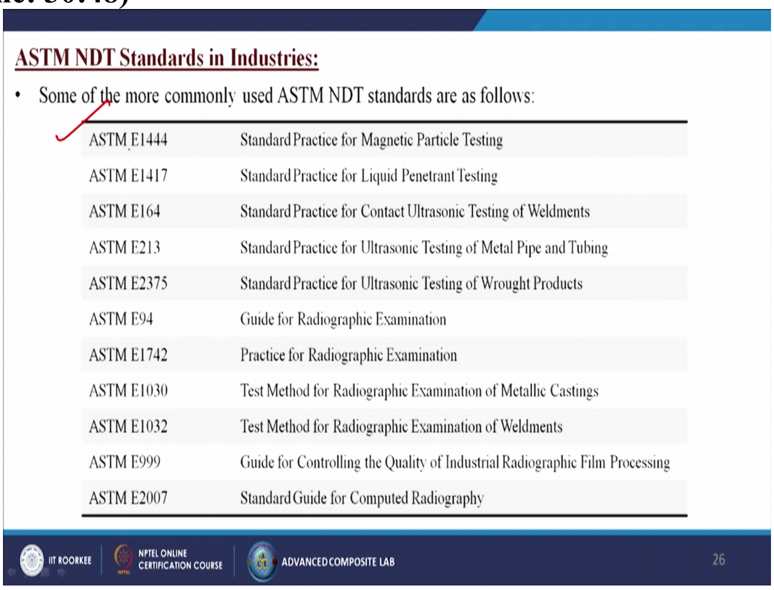

Like I can give you some examples so like ASTM E 1444 it is the standard practice for magnetic particle testing. If we talk about the E1417 it is the standard practice for liquid penetrant testing. E164 it is for the ultrasonic testing of Wellmant's, E 213 it is the ultrasonic testing of metal pipe and tubing, E2375 ultrasonic testing of rod products, E94 is the radiographic examination, E 1742 is the radiographic examinations but this is about the practice.

E 1030 it is the test method for radiographic examination of metallic castings. So, now you can see that which part or maybe what exactly I am going to measure or maybe I am going to see based on that it is having that different ASTM standards first we have to search those standards then we have to read it out and it has been clearly written over there that how we have to perform those particular tests.

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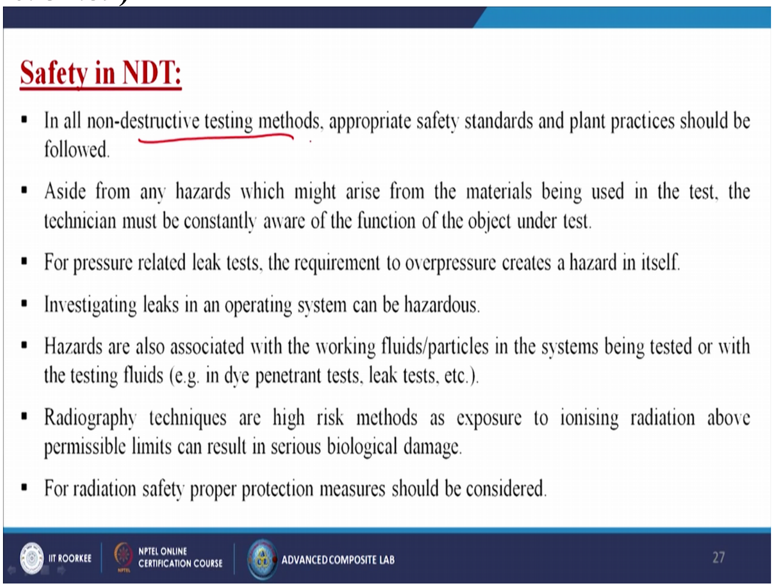

Now come to the safety in the non-destructive testing in all non-destructive testing methods appropriate safety standards and planned practices should be followed. Aside from any hazards which might arise from the materials being used in the tests the technician must be constantly aware of the function of the object on that test. For pressure related leak tests the requirement to overpressure creates a hazard in itself.

Investigating leaks in an operating systems can be hazardous. Hazards are also associated with the working fluids particles in the substance being tested or with the testing fluids. Radiography techniques are high risk methods as exposure to ionizing radiations about permissible limits can result in serious biological damage for radiation safety proper protection measures should be considered that means being a human being what kind of precautions we need to take for carry out this kind of testing.

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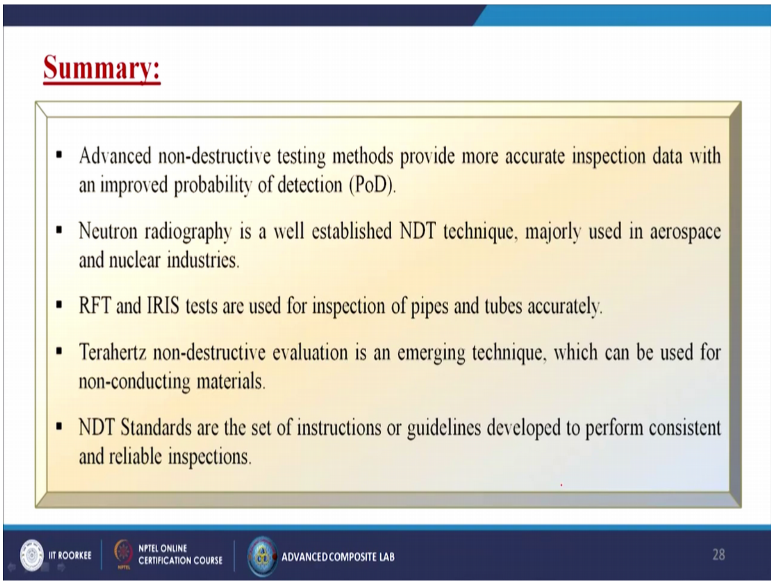

Now we have come to the last slide of this particular lecture so in summary we can say that advanced non-destructive testing methods provide more accurate inspection data with an improved probability of detection that means we are getting more precise results more accurate results by applying this kind of advanced non-destructive testing. Neutron radiography is a well-established NDT technique majorly used in aerospace and the nuclear industries.

RFT and IRIS tests are used for inspection of pipes and tubes accurately terahertz, non-destructive evolution is an emerging technique which can be used for non conducting materials. NDT standards are the set of instructions or guidelines developed to perform consistent and the reliable inspections, thank you.