Indian Institute of Technology Madras

Present

NPTEL

NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

NUCLEAR REACTOR AND SAFETY

AN INTRODUCTORY COURSE

Module 04 Lecture 01

Radiation Sources and Protection

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Good afternoon. We need to know what are the sources of radiation and should there be radiation how to protect ourselves.

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INTRODUCTION

- Radioactivity is a natural phenomenon .It may also be of artificial origin and have many beneficial applications, including uses in medicine, industry, agriculture and research as well as for nuclear power generation.
- The process of ionization necessarily changes atoms and may sometimes damage cells. If cellular damage does occur, and is not adequately repaired, it may prevent the cell from surviving or reproducing, or it may result in a viable but modified cell. If the damage occurs in a cell whose function is to transmit genetic information to later generations, any resulting effects,(stochastic) is called "hereditary".

Now it is a very natural phenomenon as I mentioned but it could also be of any artificial origin. Radioactivity exists everywhere. Everywhere there is radioactivity. We are living with radioactivity. I mentioned to you that when we take food that contains potassium 40 most of our vegetables they take the nutrients from the soil they contain potassium 40 radioactive potassium 40 and that is inside us that is already inside us not that much long before the nuclear reactors were there or the nuclear bombs were there. They are within us. We are living with them. So it's natural phenomena. Basically what we are doing it we are now using it for good effects. Of course, some people chose to use the bad effects but the precedence of the bad effect has given us a warning; beware that could be danger. So move but as the researchers progressed today it has shown that really things are not that bad as expected. Things are better but nevertheless the element of safety has got into the nuclear person so that he looks at everything with a at a safety angle.

Now the obligations, the good point of it we saw that it is being applied in medicine. You know that X-rays, CAT scan, etcetera. It has been used in industry for many purposes. It has been used in agriculture. Then waste water treatment, sewage water treatment and many other thing besides power generation. Power generation only one of them. So this multiple facets of things everywhere you are involving radiation.

So why we should be worried about radiation is very simple. Radiation has got the property of ionizing things, ionizing the atoms and our atoms, our body is also built up of so many human tissues which have atoms and different types of tissues and it can sometimes damage the cells beyond if the activity is beyond a certain level. But somehow in our system natural system of all human beings there are cells dying, there are production of new cells. This is a continuing process. Some of the body has got a way of throwing of the dead cells and creating. It's God-given thing.

Now it has been noticed that if your radiation level goes beyond a certain say threshold you may have cellular damage. Cells can get damaged. And as I said the body's repair mechanisms it may throw off those cells. So it may not allow them to what you call multiply. In fact the good cells multiply. The bad cells do not multiply. But let us say should it multiply then in a very rare case it could transmit a genetic information to the next generation and you could have some genetic disorders also. but it does not mean that it is going to happen it can happen so we must take enough precautions at every stage of all our utilization or applications in medicine, industry, agriculture that we have to take care to minimize the amount of radiation and see to it that we are adequately protected. One thing we have seen, take X-ray per se you have got so many X-ray clinics. These have proliferated in large numbers. We have a very large population but mind you the person who takes the X-ray if he is not knowledgeable about the ill-effects of radiation, he may get some problems. So it is very important that not only the person whose X-ray is taken and the person who takes the X-ray everybody what you call as the radiation worker has to be protected adequately.

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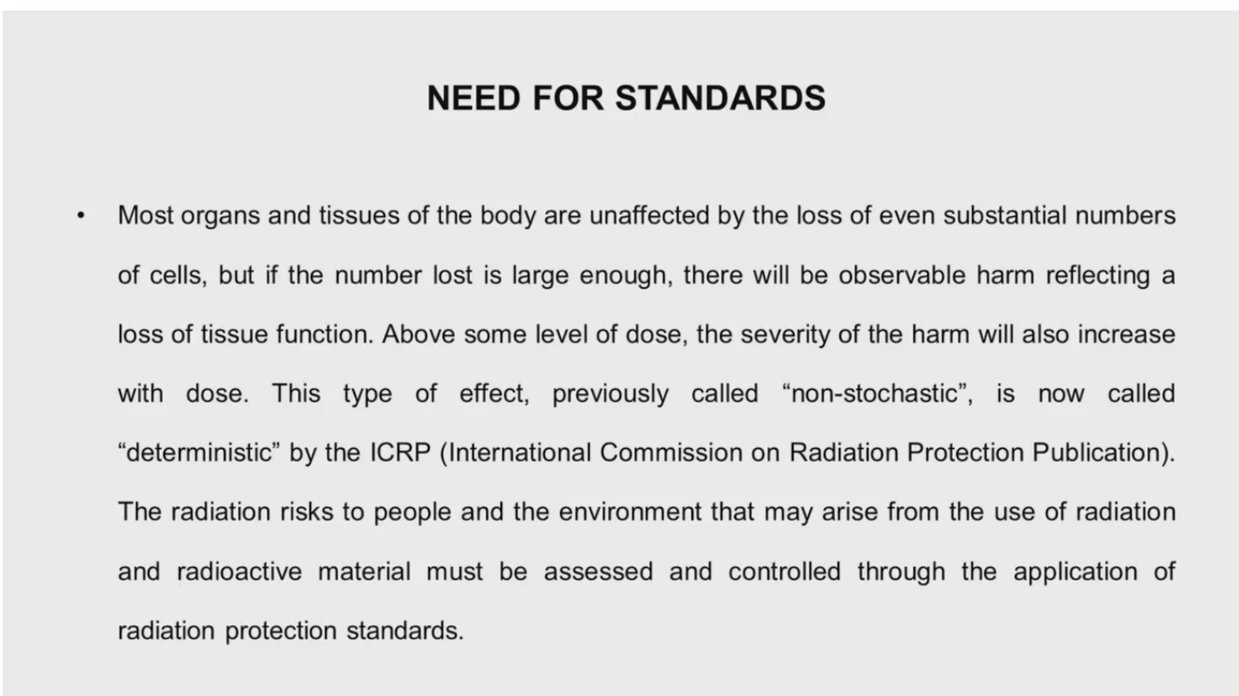

So in other words there is need for some standards. Now let us get into the background. We saw something called as genetic. Now we have different types of organs, different tissues in our body. Now the harm or the damage it does may not be same and one thing is clear higher the dose, the damage may be higher. That sort of a linear relationship is there. Of course, to differentiate the genetic and the linear this linear thing is also called as the non-stochastic effect. So it has to be kept in mind the tissues are different. Organs are different everywhere. So lot of studies have been carried again subsequent to the Hiroshima, Nagasaki bombings and the whole data has been collated by the International Commission on Radiation Protection called acronym ICRP and it has brought out lot of standards by which it tells what is the limit for each and every organ it tells what should be the level of activity for an occupational worker or a public all these things have been covered and for your information even now after nearly 60 years still we are the survivors of the Hiroshima, Nagasaki bombings, still the collection of data is going on and of course now added to that we are now following up the Chernobyl and the Fukushima disasters in which lot of activity was released. The picture is not that bad as we have thought.

Now again as I said we have to follow these standards foolproof. Foolproof following of the standard is very important. Now you might ask how do you implement these standards. In fact, this is a very important criterion or regulation that every regulatory authority in every country regarding in the nuclear field enforces. You have what is called as a health physics personnel. This health physics personnel monitor the dosages received by different persons and monitor these people in case they have taken a larger doses. So this is a very important aspect and they do constitute a good number in all the nuclear establishments.

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RADIATION DAMAGE

- Radiation deposits energy in the medium in which it passes through ionization of the medium, which may sometimes cause damage. This damage can be acute if a high level of radiation dose is delivered in a short period of time. In such a case the dose delivered per unit time is so high that the material does not get enough time to repair the damage. The acute damage always depends on the time integrated energy deposited by the radiation. If the energy deposition time is shorter than the repair mechanisms, acute damage can occur. Hence the safe practice is to use dose and dose rate to refer to the integrated energy deposited and the energy deposited per unit time respectively.

Now how does radiation damage? We mentioned that radiation is after all a form of energy. So when radiation passes through our tissues it deposits some energy in that tissue or that cell. Now depending on the energy level it can cause a damage. If it is a very short time it may not cause a damage but if the activity is high even for a short duration there could be a damage. Now basically our body has got as I mentioned tendency to repair the damage or push out the bad cells but suppose it is not able to repair, the time is so short it may not be able to repair then what happens, damage does occur. So what you get from this is you have to look at the energy into time. It is not energy alone, energy into time aspect. Integral of energy into time.

So that is what tells you that integrated energy which is deposited is what can be responsible for the damage. To assess the damage this is what we should look. So we look at two things in all this radiation effects. We look at the dose, severity of the activity which a person receives and also the time in which he is exposed to that radiation. The total two, both of this dose and the dose rate both we need to look at.

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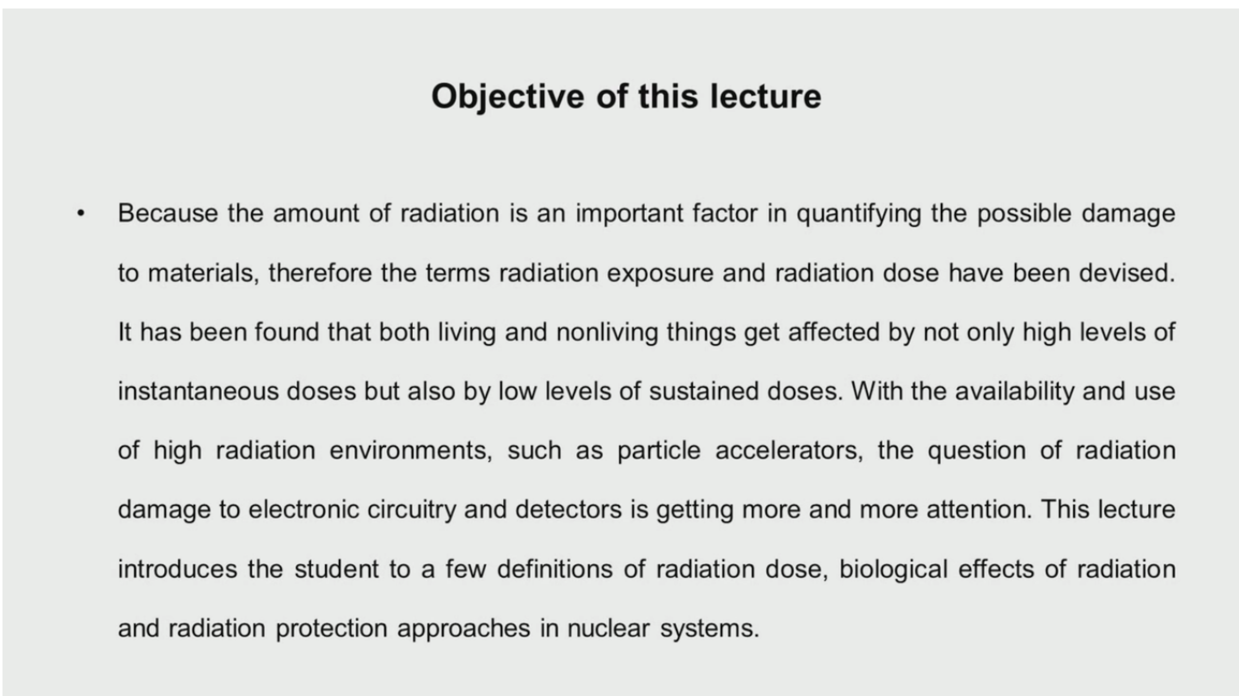

Now because of the fact that radiation is a important factor for the possible damage, we need to define certain terms. The ICRP has coined certain terms called as radiation exposure and radiation dose. The studies which have been carried out show that both living or nonliving things do get affected not only by the high levels of radioactivity and also as I said the sustained level of radioactivity. Again the time factor. Now -- so we will today, in this lecture, focus on what are all the terminologies which we come across in this radiation protection and also look at the biological effects which can cause and finally we will just touch upon the radiation protection approach.

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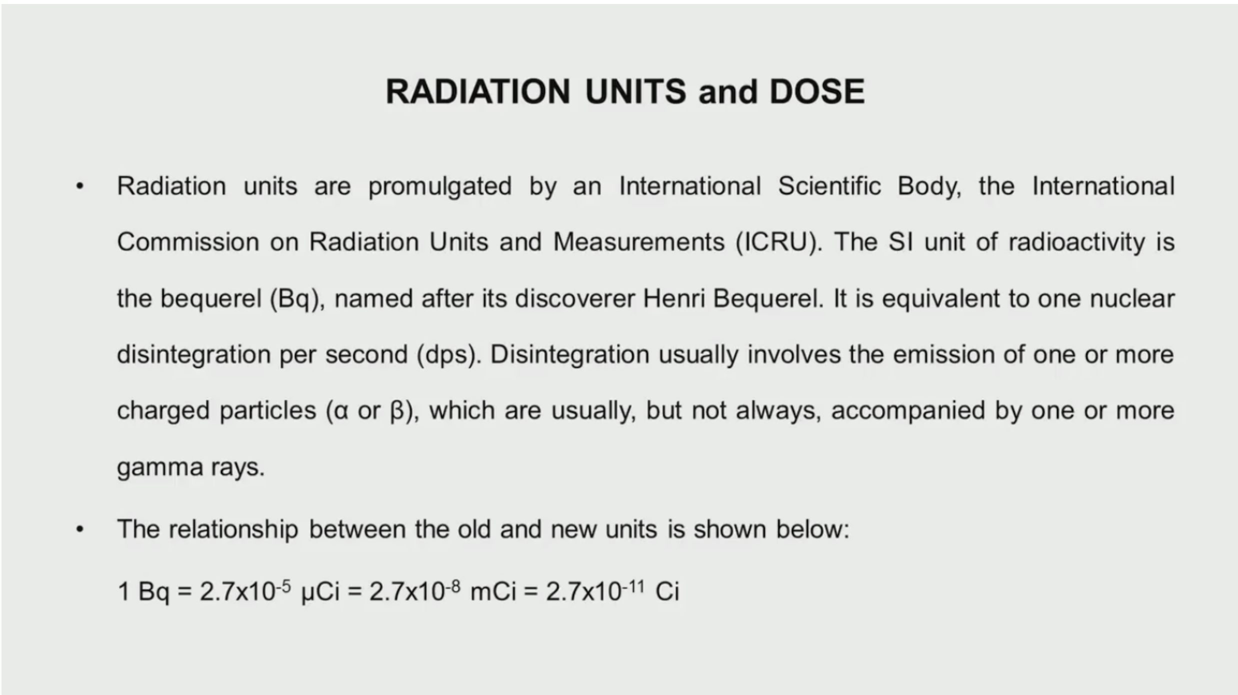

Radiation units are all arrived at by a body which is called as the International Commission on Radiation Units and Measurements and the unit of radioactivity, of course, we talk about now the standard international units, the SI unit, we call it as a Becquerel. It is named after the great scientist Henri Becquerel and very easy one Becquerel is equal to one nuclear disintegration per second. one disintegration is one per second is one Becquerel.

Now in disintegration what you have it involves emission of one or more particles. Let us say your radioactivity limit is there it could be given alpha, a beta or a gamma. So it disintegrates. There earlier to the SI units we have been using a unit called as Curie after the famous Madame Curie and Pierre Curie we have been using a unit called Curie and the relationship between the old and the new units is given here. One Becquerel is equivalent to $2.7X10^{-11}$ Curies.

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Exposure-Dose

- The term **exposure** is used to describe either an X- or gamma-ray field incident on the body at any point. The presence of gamma rays at the surface of a body can be measured in terms of the number of ions of electrons produced in the nearby atmosphere. This measure of the radiation field is especially useful in the concept of radiation protection since the biological effects of gamma-rays is a function of the ionization they produce in a body. Strictly speaking, amounts of energy absorbed by a subject are not necessary the same as the amounts of energy it is exposed. To tell them apart is very difficult. Amounts of radiation energy exposed to or absorbed by a subject are called **doses**.

Now let us look at the term called exposure. What does this mean? What is exposure? We use the term exposure to describe when a body is being given an X-ray or Gamma ray at any point. So how do you measure their exposure? It is measured in terms of the number of electrons which are produced in the tissue or in the atmosphere. So this exposure is a measure of the ionization potential of the alpha, beta, or gamma ray. So it is a potential. So this potential or measurement is widely used and we are able to talk about what is the exposure of a person. But strictly speaking the amount of energy absorbed by a organ or tissue need not be the same as the radiation that is exposed to because this room may have a certain radiation exposure. I could be in an area where I am giving only a small amount. So it has got ability to ionize but I am only in a very small area of its influence. So there is a difference. So to tell this apart the amount of radiation energy absorbed by the subject is called as dose. We say how much dose he has received.

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Absorbed dose

- When radiation is incident on a material, it will deposit energy in that material through a variety of interactions. Therefore, a useful measure of the amount of radiation that a material has received is the quantity called absorbed dose. Absorbed dose, D, is defined as the mean energy imparted by ionizing radiation to the matter in a volume element, and divided by the mass of the matter in that element.
- The unit of absorbed dose is the gray (Gy), which is equal to the energy deposition of 1 J/kg. Some countries still use an old unit called the rad (1 rad = 0.01 Gy).

Now when the radiation is incident on a particular material as I said it will deposit energy. Now this energy which is received by the material is called the absorbed dose. And in a strict definition form it is a mean energy imparted by the ionizing radiation to the matter in one volume of the element divided by mass of that element.

So remember it is the mean energy imparted by ionizing radiation in unit in a volume element divided by the mass. So this is called by the unit gray in SI units and it corresponds to deposition of one Joule per kg of the material or the tissue. So if one Joule is deposited in a one kg of the tissue then we say he has – it is absorbed dosage one gray. Again earlier we use the word rad so that one rad is equivalent to 0.01 Gray. People use when the absorbed doses are less we use micro gray and still milligray. We still use lesser types of units but so gray is absorbed dose.

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Equivalent dose

- The absorbed dose is not capable of characterizing damage to any medium. All it tells us is how much energy has been absorbed by the medium and not what this deposited energy has done to the medium. In this respect absorbed dose treats all types of radiation equally. In other words, for the case of absorbed dose, there is no difference between a photon and an α-particle if they deposit the same amount of energy. Hence when it comes to the effects of radiation, one cannot use absorbed dose as the relevant quantity. Since dosimetry is primarily concerned with the safety of personnel, a quantity called **equivalent dose** has been defined that characterizes the damaging effect of radiation on tissues. The basic idea is fairly simple: multiply the **absorbed dose** by a factor suited to the **biological effectiveness of the particular type of radiation** and the location of its source.

Now we have another terminology called the equivalent dose. This concept has come essentially as I mentioned in the beginning the fact that suppose I say you have a material or an organ. It absorbs this much dose. So it just tells you this this amount of energy has been taken up by the body or the material, any material let us say. Now this does not tell you whether it is a neutron, energy due to a neutron, whether energy due to a proton or energy due to any other particle. But mind you the effect or the damage is not same for a neutron and a proton or alpha or beta of the same energy. It is not same.

So when we are talking about just dose per se we have to know what is the ray or neutron, whether it is neutron, whether it is proton or what it is causing so that is why we call a terminology called as equivalent dose. So we have the absorbed dose and the equivalent dose and to get the equivalent dose from the absorbed dose we have to multiply it by an effectiveness factor which is for that particular type of radiation. So then we get the equivalent dose.

So we saw the terminologies **exposure-dose**. We saw the absorbed dose. Now we have come to the equivalent dose which is absorbed dose multiplied by the effectiveness of the particular type of radiation.

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Quality Factor-Radiation

TYPE OF RADIATION	QUALITY FACTOR
X-rays, γ rays	1
Electrons	1
α particles	20
Fission Fragments	20
Heavy Nuclei	20
Protons	5-10
Neutrons with E<10keV	5
10-100keV	10
100kev-2Mev	20
2-20 Mev	10
>20 MeV	5

This table we will go through just to give you what is that factor, multiplication factor, for X-rays and gamma rays which are similar. It is one for electrons, it is one. For alpha particles it is 20. So you can see alpha particle within a system has a higher sort of you know can cause higher damage. Fission fragments is about 20. Heavy nuclei also protons in the range of 5 to 10 and neutrons depending on their energy they have got 5, 10, and then for a very large energy the time is less, the quality factors are less. So here this quality factor multiplied to the absorbed dose is going to give the equivalent dose.

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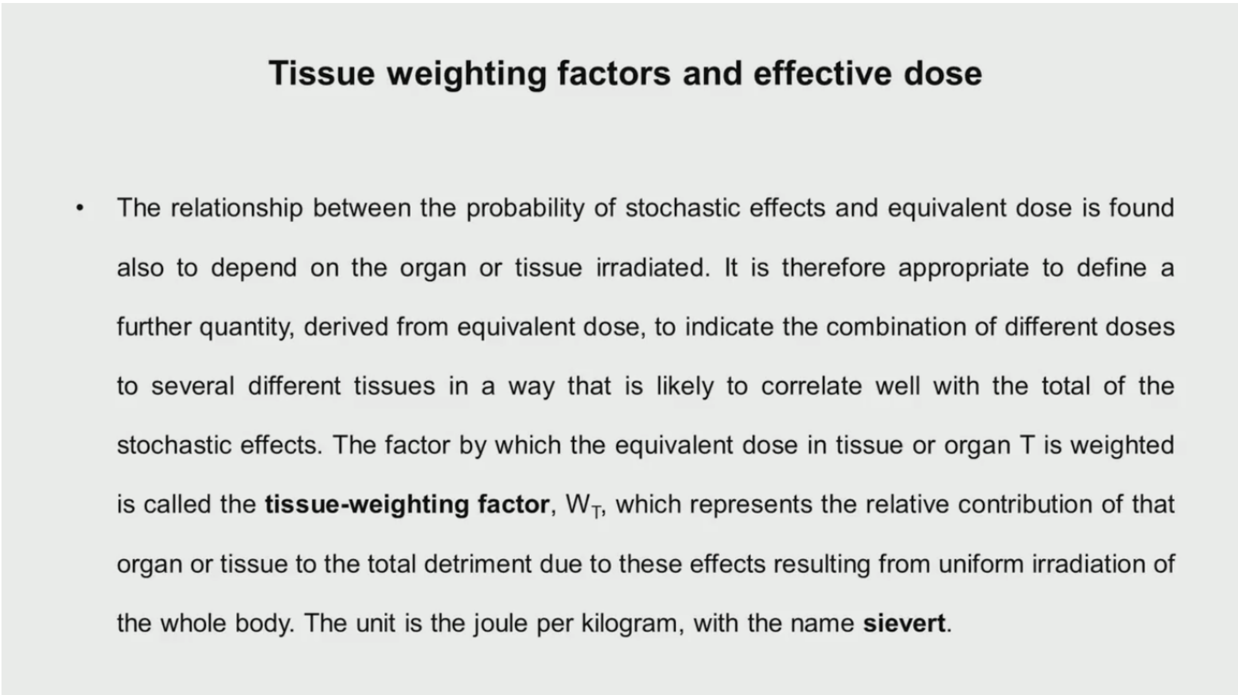

Now we saw the equivalent dose okay. So we know what is the equivalent dose. It is body is getting but now there is the other factor. All tissues do not respond to the radiation or do not get damage to the same level by the radiation. So that means we need to define something like a factor which quantifies how much the tissue can take. So there is another factor called as the tissue weighting factor. So now you look we had the absorbed dose. Then we had the equivalent dose. After the equivalent dose still we are not come because we should look at the particular tissue which is getting affected. So we need to know the response of the tissue. So the tissue weighting factor is the other one and again these are only factors. The unit does not change. The unit is still Joules per gram. With this multiplication we have what is called as the Sievert. Again we have millisieverts and micro sieverts being used.

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Tissue Weighting factor

Issue/Organ	Tissue Weighting Factor
Gonads (testes & Ovaries)	0.2
Bone Marrow	0.12
Colon	0.12
Lung	0.12
Breast	0.05
oesophagus	0.05
Thyroid	0.05
skin	0.01
Bone Surface	0.01

You see the different tissue weighting factors for the Gonads means basically the reproducing organs in men and women. It is about 0.2. bone marrow it is less. Colon it is less. When you come to the breast it is still less because it contains more of soft tissues. Oesophagus about 0.05. Thyroid again 0.05. Skin is about 0.01. Here you see this reproducing organs have got a higher weighting factor. So normally it is a practice or a standard followed in all our nuclear establishment that when a woman is pregnant we try to keep her off or limit her presence in areas which is having some radiation activity. In fact you might know in many cases pregnant when they take ultrasound scans. They try to avoid X-rays as much as possible unless there is an emergency.

So you see many of the things are automatically getting applied that we are not aware of that why standards are being followed. So in these lectures my main aim would be to give you an awareness of how these are already getting implemented and it is all standardized not that just we are not going in a zigzag fashion. It is all standardized and based on enough studies carried over 30 to 40 years.

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Natural background radiation

- Everyone is exposed to low levels of radiation all the time. Natural radioactive isotopes in the earth (primarily uranium, thorium, radium and potassium) and cosmic radiation constantly immerse us in a field of natural radiation. The atmosphere acts as a filter and reduces considerably the amount of cosmic radiation reaching the earth's surface. This filtration means that the dose at sea level is less than at high altitudes. The external dose contribution from terrestrial sources is also very much dependent on the geology. For example, there are parts of India and Brazil where people are receiving much higher than average dose rates. . Potassium-40 is a naturally occurring radioisotope that becomes incorporated into our food, and hence into our bodies, exposing us continually.

Now okay we are talking about all those radioactivity due to natural or due reactors and all. What about the natural background radiation which is present? As I mentioned radiation is present everywhere. We are living in a radioactive earth but for the radiation decay which is happening in the earth due to our uranium and thorium present, the temperature of the earth will go down and maybe we would not have been living here now because you require a certain temperature to live. As I mentioned in the first few lectures that the heat loss from the earth's surface is getting compensated by the heat generated due to the decay of this radioactive decay of uranium and thorium inside the Earth's mantle. Now primarily uranium, thorium, radium and potassium all these are the naturally occurring and we get the radiation, cosmic radiation also gives some input to that. Now the cosmic radiation comes from the cosmos from up. As it comes down there is a attenuation or filtration of the radiation. What do I mean by this? I mean higher the altitude or higher you are away from the earth, above the earth not away, higher you are above the earth you will have a higher level of activity or radiation you would be exposed. As you come down and come close to Earth it will be less because of the cosmic radiation.

Now so at sea level you are having less, at higher altitudes you are more. Then you also have from within the earth depending on the geology suppose you are living in an area like the Travancore sands in Kerala, the thorium is there. monazite sand are there. There the activity level maybe more. So geological things also do matter. Again in some parts of Brazil also you have got lot of monazite and there people receive higher than the average dose rates. So but of course people are living there. Of course something has in common. Both Brazil coffee is grown in India in the other side also coffee I think maybe I do not know that coffee has got certain things to do with radiation but I am told in Internet when I see that taking one cup of coffee is equivalent to some Curies of radiation. That is what I see.

Now potassium-40 is again a naturally occurring isotopes. I have mentioned it to you and this gets into our food into our bodies. The other day I was just trying to see okay everything is coming to the foodstuffs. Let me see which vegetable takes more radiation, more potassium-40 . So I found that cabbage has got a greater affinity to take the potassium-40. Of course we are taking cabbage normally. Everything is okay. There is nothing to worry. So whenever it is a naturally occurring nothing has happened. We have been living. So remember our bodies are continuously getting bombarded by radiation but we are living with it.

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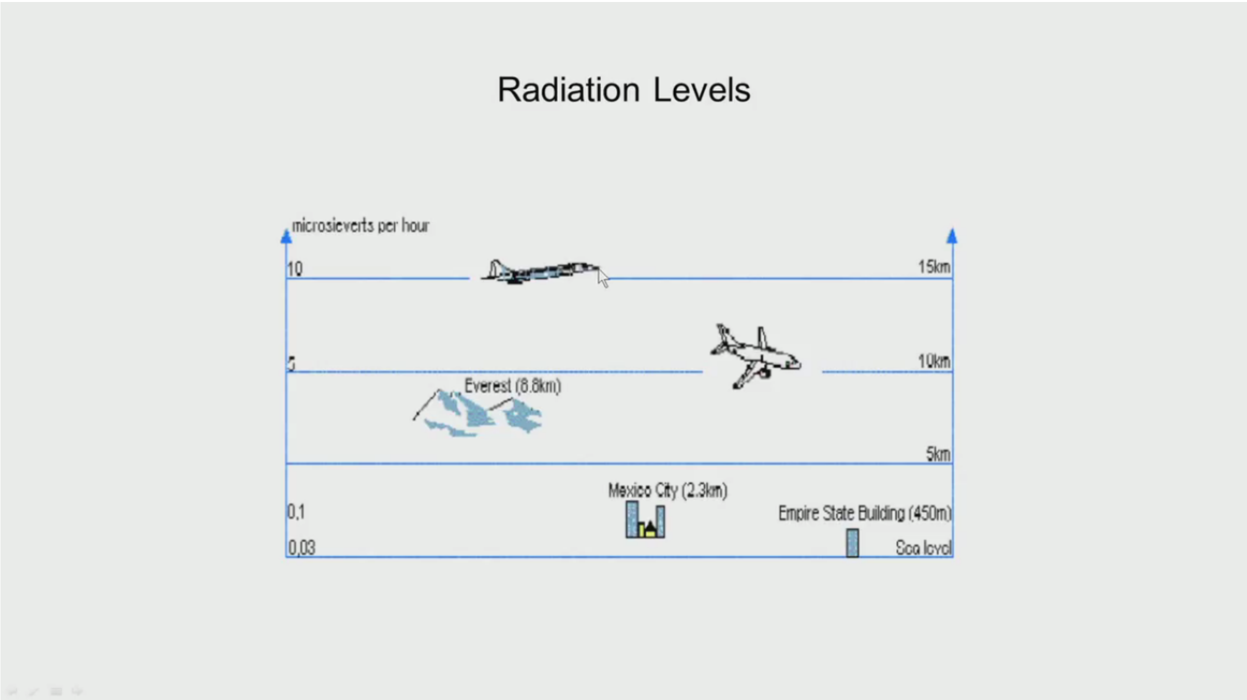

this is to show you pictorially what I mentioned now. If I say I am flying in the aeroplane at a very large height about 15 kilometers from the earth's sea level I get about 10 microsieverts per hour. About 10 kilometers I get still less. Further down I get still and still less. So higher the level I get much more.

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Average annual natural background radiation

	Effective dose (mSv/a)
External	
Cosmic	0.36(1.2 mSv/a Denver,USA)
Rocks, Soil	0.41(20mSv/a,India, Brazil)
Internal	
Pottassium-40	0.18
Radon	1.42
Total	2.4

So now let us take stock of what is the average annual natural background radiation. One, the external which we talked coming from the cosmic or from the soil. The geological thing. It is about 0.36 millisieverts per annum. This is average but there are some places as I mentioned where in Denver high cosmic radiation is very high, 1.2 millisieverts and coming to the geological thing, again average is 0.41 but in places in India and the Trivandrum and Brazil it is as high as 20 millisieverts per annum.

So this is the external. Then the internal is due to our consumption of the foodstuffs. Potassium-40 that comes and the radon and the average annual dose is something like 2.4 millisieverts per annum.

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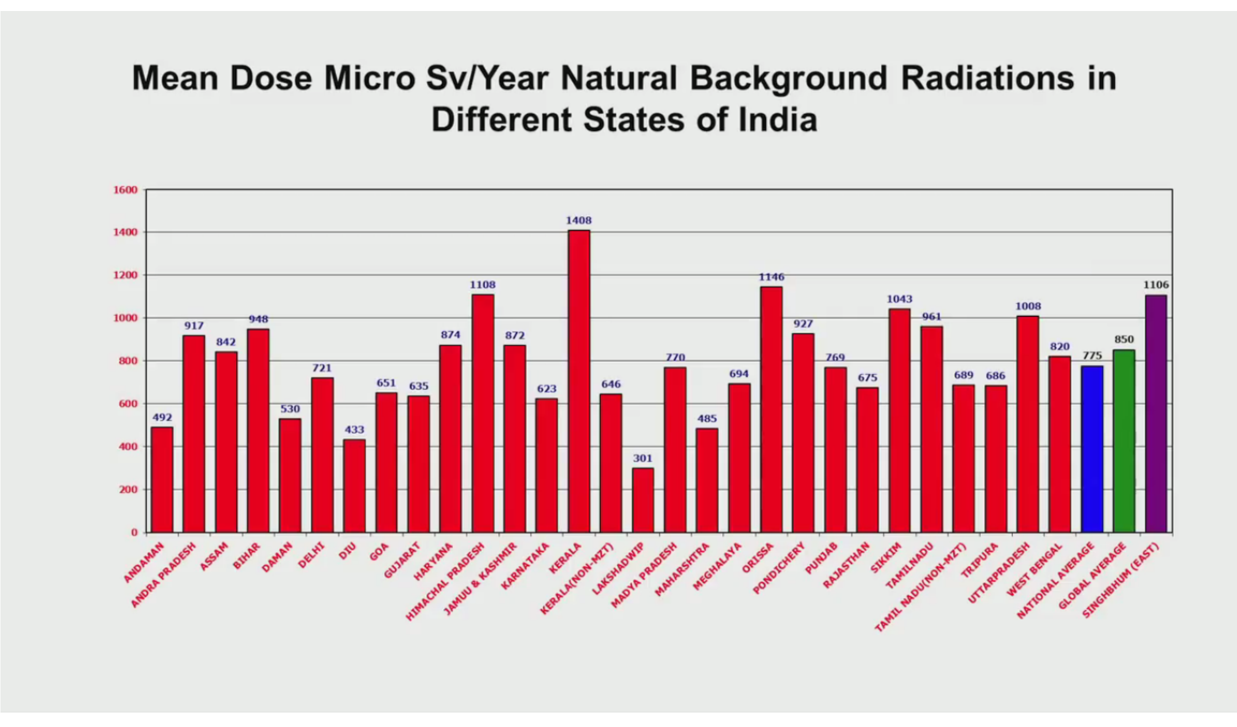

Now after the setting above the atomic emission and you know having lot of universities taking part in surveys radiation, surveys, etc. This is a average dose rate in microsieverts per year which is a natural background in the different states of India. Starting with A of course, Andaman, and we go further if you see Kerala it shows a peek then let us look up Himachal Pradesh shows about 1108 microsieverts per year. Orissa about 1146. Then let us see any other about 1043 Sikkim. 1008 is Uttar Pradesh. Singhbhum 1106. Here there is you must have to relate something. I mentioned you in the initial lecture first lecture itself that coal contains uranium and thorium because it is scattered throughout the Earth's crust. So uranium and thorium also exist with coal but unfortunately we are not aware that this uranium and thorium are there. They are not very high levels but still they are burnt. These products are released into the atmosphere or go to the ash and we saw the ash pond in some of the thermal power stations are high and on an average a coal-fired power station emits 100 times the radioactivity of a nuclear power station of a similar capacity. The reason is in nuclear we take precautions. There it is not taken, other side is not. But we have been living with it. So here again if you see coal Singhbhum contains lot of coal that is the reason there your activity is high.

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Naturally occurring Radio-nuclides

Nuclides ($t_{1/2}$ ~ 10^{6-15} y)	**Radiation**
$^{235,\,238}U$, ^{232}Th and off springs	α, β, γ
^{144}Nd, $^{147,\,148,\,149}Sm$, ^{152}Gd, ^{186}Os, ^{190,}	α (γ)
^{40}K, ^{87}Rb, ^{115}In, ^{123}Te, ^{138}La, ^{176}Lu, ^{187}Re, ^{210}Bi *etc.*	$β^+$, β, EC (γ)
• Nuclides produced by cosmic rays	
^{14}C (5730 y), ^{3}T (15 y), ^{7}Be (53 d), ^{10}Be (2.7×10^{6} y)	β

Now let us see which are the naturally occurring radio nuclides and their half-lives of the order of 10^{-6-15} years because uranium 235, uranium 232, thorium 232 238 and thorium 232 and their products and all of them are alpha, beta, and gamma emitters. Then we have other elements of the periodic table. Samarium, Beryllium which are alpha emitters of course little bit of gamma. Then the third set is potassium-40, Rubidium, Tellurium, Lanthanum, Bismuth, etc. and they are all beta emitters and then some of the nuclides are produced because of the cosmic rays. There is carbon-14, then Tritium, then Beryllium-7 and Beryllium-10. They have half-lives of the order of

$10^{2.7\text{-}6}$ years. They are all beta emitters. So this is to give you an idea of what sort of raise they are emitting so that we must know how to protect ourselves.

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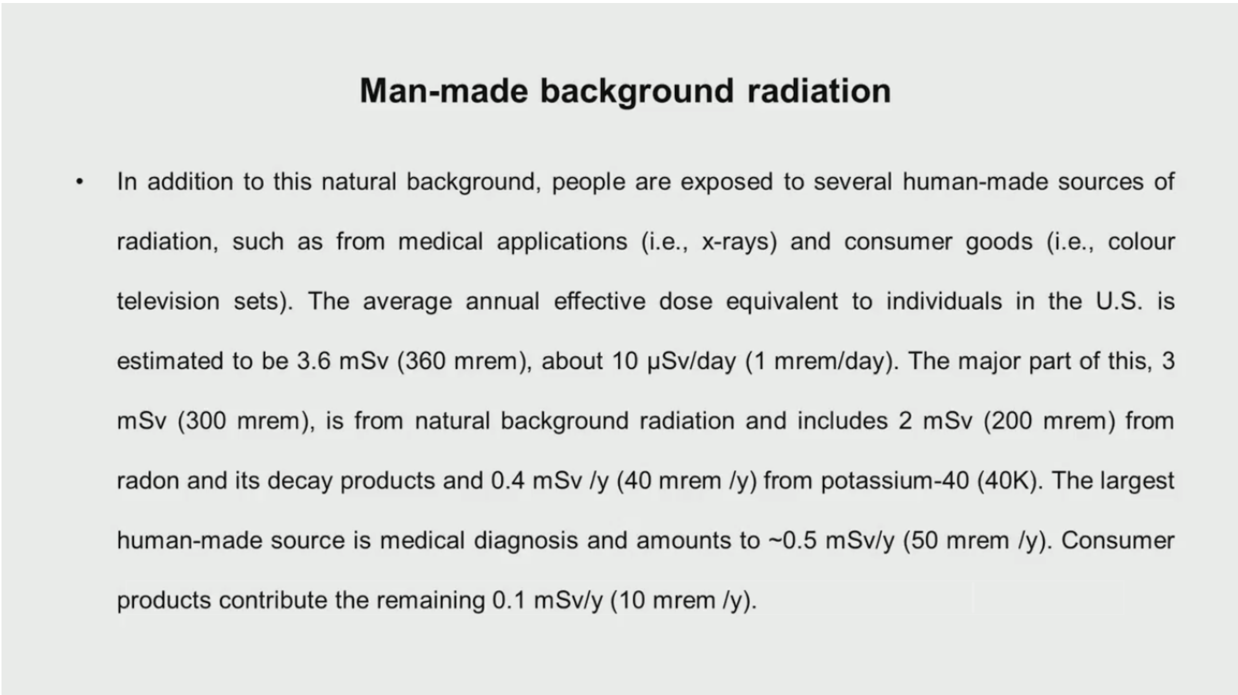

So we saw the natural radiation background which exists whether we do anything or not. Then what are the man-made? Medical applications. We saw lot of usage including X-rays, CAT scan, etcetera. So there you can get exposure human beings. As I said the doctor or the radiologist who is taking the X-ray who is doing the well he has to take care besides he should give proper dosage to the person. Then color TV sets; many of them have give out radiation is normally we are told that do not sit very close to your TV and watch. There is a meaning behind it. Even though we feel that being very close we are able to see very effectively it is not correct. So in this way you get a lot of external radiation which is man-made I can say. This total effect is something like total is about man-made background radiation in USA something like 3.6 millisieverts and about 10 microsieverts per day.

So again the major part of this is basically from the natural background radiation and other things are from the decay of potassium-40 which is in the soil but the major amount is contributed by the medical diagnosis which really is a big amount, 0.5 microsieverts -- millisieverts per year or 50 milligram per year. This is because there is extensive usage of radiation in diagnosis. Medical diagnostics is today will be absent without radiation.

So really speaking it is very important and you might be aware that a another thing has emanated called as medical physics wherein the person studies the effect of all these radiation and its application in medicine. It is a very very important and area where the job prospects are good. I can tell you if you just take this medical diagnosis in USA it is something like a $400 million business. Just take okay you stop these medical diagnosis you do not know how people will diagnose and how many people will be out of jobs. So it is unknowingly we have not only taken care of very good diagnostic schools we have produced. We have also given employment opportunities. Consumer products do give but not a very high. It's about 01 millisievert per year. These are all average values.

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Exam	Effective Dose mSv (mrem)[2]
Mammogram (four views)	0.7 (70)
Dental (lateral)	0.02 (2)
Dental (panoramic)	0.09 (9)
DEXA (whole body)	0.0004 (0.04)
Hip	0.8 (80)
Hand or Foot	0.005 (0.5)
Abdomen	1.2 (120)

Complete Exams	Effective Dose mSv (mrem)[1]
Intravenous Pyelogram (kidneys, 6 films)	2.5 (250)
Barium Swallow (24 images, 106 sec. fluoroscopy)	1.5 (150)
Barium Enema (10 images, 137 sec. fluoroscopy)	7.0 (700)
CT Head	2.0 (200)
CT Chest	8.0 (800)
CT Abdomen	10.0 (1,000)
CT Pelvis	10.0 (1,000)
Angioplasty (heart study)	7.5 (750) - 57.0 (5,700)[3]
Coronary Angiogram	4.6 (460) - 15.8 (1,580)[3]

You can just see how much you get in a mammogram. Mammogram is the X-ray of the best. You take in different angles to conclude whether there is a tissue growth or not. Of course later if there is a tissue growth even there you give radiation to kill the tissue if it is cancerous. Now you get about 0.7 millisieverts is the effective dose. Then many times when you have our teeth examined, teeth X-ray. It's a small one. We put in a small film we get about 0.02 millisieverts. Then if you sometimes the whole body scan is taken it is not much as about 0.0004. Abdomen, abdomen when you take an X-ray it's about 1.2 you know why abdomen is normally not very transparent to X-rays. So when we want to have an x-ray you put Barium. You take Barium inside. Barium meal is given to you and with Barium inside in the stomach it is transparent to the x-rays and you can take but then because of presence of barium you have to have a higher dosage. You get 1.2.

So you can see how much you are getting in a Barium meal X-ray. Remember do not just insist on a Barium meal X-ray unless there is really something important. Then you see the other type of examinations as I said. Barium swallow 24 images, 1.5 millisieverts. Then CT scan of the head to CT scan of the chest 8. CT scan of the abdomen 10. Then angiogram when you take it varies a good amount angioplasty where the coronary bypass where you use the radiation. It is about. So we must remember that the medical diagnostics are an important place where you can be subjected to radiation and we need to take very important what you call precautions and follow the standards to protect ourselves and the public by suitable shielding. Thank you for your attention.

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