Power Plant Engineering
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Lecture – 26
Principles of Nuclear Energy

Now, in a coming few lectures, we will discuss about the Nuclear Energy, Nuclear Power Plants. So, before we start with the nuclear power plants, I will like to brush up the memory of nuclear science, starting from the Structure of the Atoms, Chemical and Nuclear Reactions, Nuclear Stability and Binding Energy, Radioactive Decay Half Life, Nuclear Fission, Chain Reaction.

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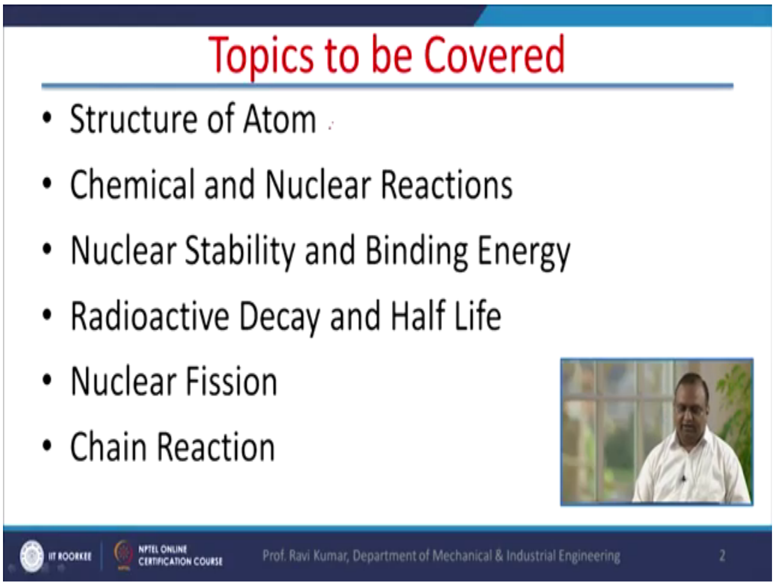

Topics to be Covered

- Structure of Atom
- Chemical and Nuclear Reactions
- Nuclear Stability and Binding Energy
- Radioactive Decay and Half Life
- Nuclear Fission
- Chain Reaction

Because nowadays, our power generation is mainly dependent on hydropower and thermal power. We have sufficient reserves of coals; coal, but the issue is related with the emission of carbon. So, in future the power demand will increase, our thermal plants can meet out the power demands; but the emission of carbon which is going to the atmosphere will lead to the (Refer Time: 01:32) coal mining. So, we cannot use, though we have reserves of the coal, we will not be able to use that coal for power generation.

Now, the second is major source of power is hydro power. Now, hydro power if you go for the large day, the gestation period is quite high; it goes up to 20 to 30 years and there are environmental related issues also. Though, we can go to the small head power plant, medium or low head power plants. A highway cannot be replaced by a number of small roads, similarly a benefits of a high head dam cannot be replaced by a benefits of from the low head dams.

So, but if you go for the high head dam, then the submerged area is more and there I mean environmental related issues. Now, third option we are bulk of power is generated is left us with us is a Nuclear Power right.

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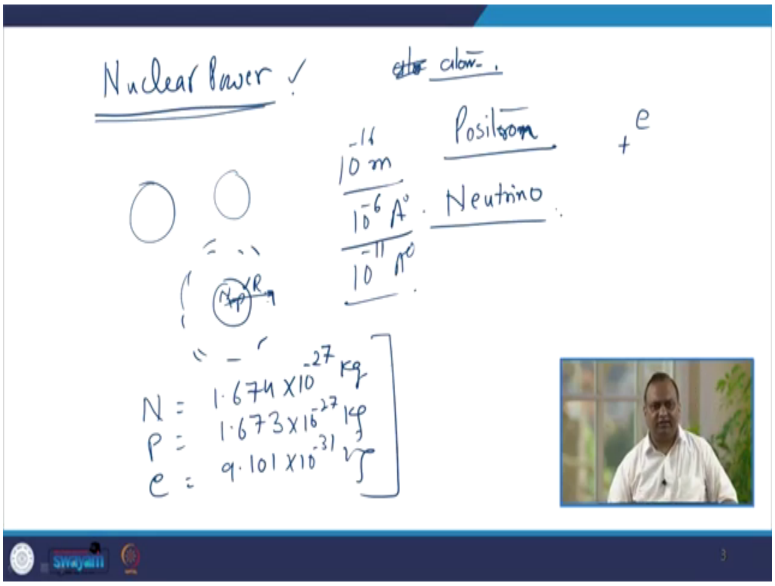

Nuclear Power ✓

~~ato~~ atom.

Positron

$_+e$

10^{-14} m

10^{-6} Å

10^{-11} Å

$N = 1.674 \times 10^{-27}$ kg

$P = 1.673 \times 10^{-27}$ kg

$e = 9.101 \times 10^{-31}$ kg

Nowadays, there is a lot of emphasis on the solar power as well. But right now, it is ok, but we do not do after down the 20-30 years when these solar panels will become, I mean they will live their life. So, disposal of solar panel may also become an issue. Now, in solar power also by say localize heating, we are also creating localized hotspots and that may also change I mean change the environment of a particular locality. I mean these studies have to be carried out, I mean we are not very sure about them.

But for nuclear power, we are very sure. There are issues with related with the nuclear power also I mean maybe it is the disposal of the used fuel and a lot of work that research work is going on regarding the disposal of the used fuel. But still it can be considered as a nuclear power because it does not add carbon to the environment. Let us go back to the topics to be covered here.

So, we will start with the structure of the atom. So, we know the all the matter composed of the unique particle that is known as atom and you must have studied a lot about the structure of the atom. I need not discuss. There is a nucleus consisting of neutron and proton surrounded by the electrons right and when we talk about the material which is used for the nuclear power plant, it is a radioactive material. So, radioactive material we will take up later on.

Let us talk about the size of the atom. Let us have some physical idea about the size. So, normally the radius of the nucleus is the order of 10 to power minus 16 meters. It is 10 to power minus 6 angstrom. Angstrom will also a unit. So, it is 10 to power minus 16 angstrom and if you go for the radius of the atom, then it is 10 to power minus 11 angstrom. So, there is a large gap between this and this right.

Now, after this the radius of the nucleus and the radius of the electron, the nucleus consists of the neutrons, the mass of a neutron is 1.674 into 10 to power minus 27 kgs. Mass of a proton is 1.673, its approximately same; 10 to power minus 27 kg. But mass of the electron is much much less 9.101 into 10 to power minus 31 kg. It is much much lesser than this.

And the elements which are same number of protons have a same type of physical properties right. There are other elements also, other particles also which are known as positrons; positron. Positron is positively charged electron, that is known as positron. Neutrino, is the tiny particles, they are rejected, they ejected the beta particles; they are known as neutrinos. Now, there are two types of reactions; chemical reaction, nuclear reaction; the heat is also liberated in chemical reaction.

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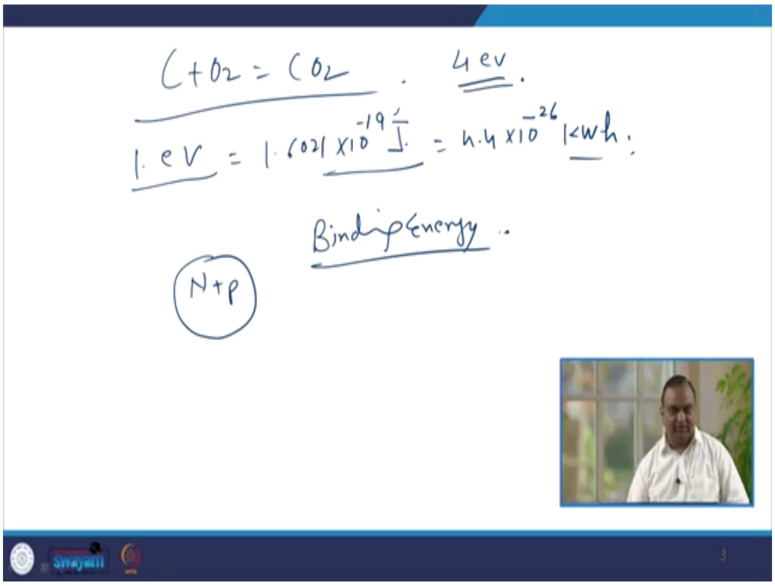

$C + O_2 = CO_2$. 4 eV.

$1 \text{ eV} = 1.6021 \times 10^{-19} \text{ J} = 4.4 \times 10^{-26} \text{ kWh}$.

Binding Energy ..

N+p

Suppose, we take C plus O2, these very simple I mean you are burning of carbon oxidation of carbon CO2. Only 4 electron volt is released right and 1 electron volt, it is worth to move electron in 1 volt potential difference. So, it comes out to be 1.6021 into 10 to power minus 19 Joules is equal to 4.4 into 10 to power minus 26 kilo Watt hour. Why I am giving this figure because when we will do the calculations regarding the nuclear power plants, these figures have to be in our mind.

Now, when the size of the atom grows the number of neutron and proton increases; neutron and proton increases, at the same time number of electron also increases. And at a certain level, it becomes difficult to keep them close; especially, neutron and protons to bind them together. So, some energy is required, always not only when the size is large, but for the smaller atom also some energy is required to keep the neutrons and protons together and that is known as Binding Energy.

If binding energy is more that obvious stable; when the binding energy is less, it is it tends to disintegrate and those atoms which tends to integrate are useful for nuclear energy because when the disintegration takes place, a lot of energies binding energy itself is released right and a lot of energy is generated.

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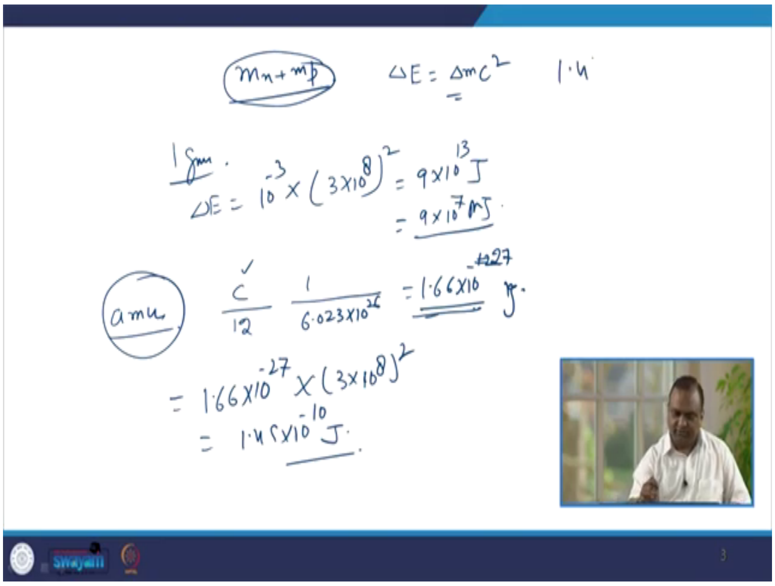

$\boxed{m_n + m_p}$ $\Delta E = \Delta m c^2$ 1.4

1 gm.

$\Delta E = 10^{-3} \times (3\times10^{8})^2 = 9\times10^{13}$ J

$= 9\times10^{7}$ MJ.

$\boxed{\text{amu}}$ $\frac{C}{12}$ $\frac{1}{6.023\times10^{26}} = 1.66\times10^{-27}$ kg.

$= 1.66\times10^{-27}\times(3\times10^{8})^2$

$= 1.45\times10^{-10}$ J.

So, if you look at the some of the neutron and proton, some of the mass of the neutron and mass of the proton, it exceeds because mass now we consider the mass can be converted to energy and energy can be converted into the mass. So, we need binding energy. So, mass of the proton and mass of the neutron if you look at, it exceeds the total mass of the electron and we are from (Refer Time: 08:57) the delta E that is known as binding energy delta m C square.

Suppose, there is a 1 gram of metal. So, delta E is going to be equal to 10 to power minus 3 because we are converting into kilograms. 3 into 10 to power 8, this is speed of light m C squared. It is 9 into 10 to power 13 Joules. It is 9 into 10 to power 7 mega Joules. Its quite high right. So, only fraction of this mass in neutron and proton which is used for converting which is converted into the binding energy and which puts together neutron and proton.

Now, there is another you need which is known as atomic mass unit amu. Now, atomic mass unit, we say we take carbon; atomic weight of carbon divided by 12 and if we take a 1 kg of carbon, it will contain as per the this is Avogadro hypothesis 6.023 into 10 to power 26 atoms of carbon right and this divided by 12, we will give 1.66 into 10 to power minus 12, sorry not 12 sorry it is 27 ok.

This is atomic mass unit. So, all the value related with the mass of particles of an atom like neutron, proton, electron is always expressed in terms of amu. Suppose, this atomic mass unit, I want to convert into the energy. So, it is going to be 1.66 into 10 to power minus 27 into 3 into 10 to power 8 square it is going to be equal to 1.49 into 10 to power minus 10 Joules. Now, this four point 1.49 next.

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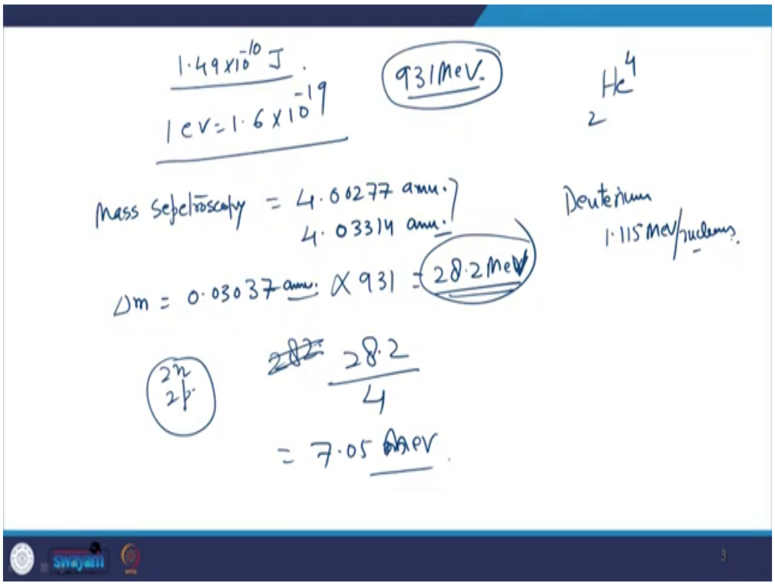

1.49×10^{-10} J.

$1\,eV = 1.6 \times 10^{-19}$

$\boxed{931\,MeV.}$

$_{2}He^{4}$

Mass Sepctroscopy = 4.00277 amu.
4.03314 amu.

$\Delta m = 0.03037$ amu. $\times 931 = \boxed{28.2\,MeV}$

Deuterium
1.115 MeV/nucleus.

$\boxed{\begin{matrix} 2n \\ 2p. \end{matrix}}$

~~282~~ $\dfrac{28.2}{4}$

$= 7.05$ MeV.

This 1.49 into 10 to power minus 10 Joules, if I want to convert this into the electron volt, then 1 electron volt is 1.6 into 10 to power minus 19 right. So, when I convert this into the electron volt, we get 931 million electron volt. So, one amu can generate 931 million electron volts, that is quite high energy. We can take one example of helium. Helium has atomic mass 4, atomic number 2.

So, it has 2 electrons, 2 neutrons, 2 protons and 2 electrons. Mass is when we do the mass spectroscopy of helium of helium, we get a mass of the helium and then, we get the value 4.00277 amu. When you calculate the mass by analytical means, we get 4.03314 amu. So, there is the difference and this difference goes in the form of a binding energy. So, delta m is equal to if you take the difference it is 0.03037 amu and if you multiply this by 931, you will get 28.2 million electron volt.

So, this is the binding energy which is available for helium. Now, helium is nucleus which has 2 neutrons and 2 protons. So, binding energy per particle is 282 sorry 28.2 divided by 4 7.05 million electron volt. It is a stable; 7 is good, good enough. I mean more is the binding energy, more is the stability of the atom. It goes up to say for iron, it is a maximum, close to the iron it goes up to eight point something it more than 8.5 right.

The moment this binding energy reduces for heavy metals, for this radioactive materials, it goes down that is why slight with the slight excitation, the nuclear disintegrate or the emission of the particles takes place. For example, for deuterium, the binding energy is only 1.115 and million electron volts per neutron per or nucleons. It is so low. So, for example, we can take uranium, 238, atomic number 92, atomic mass 238.

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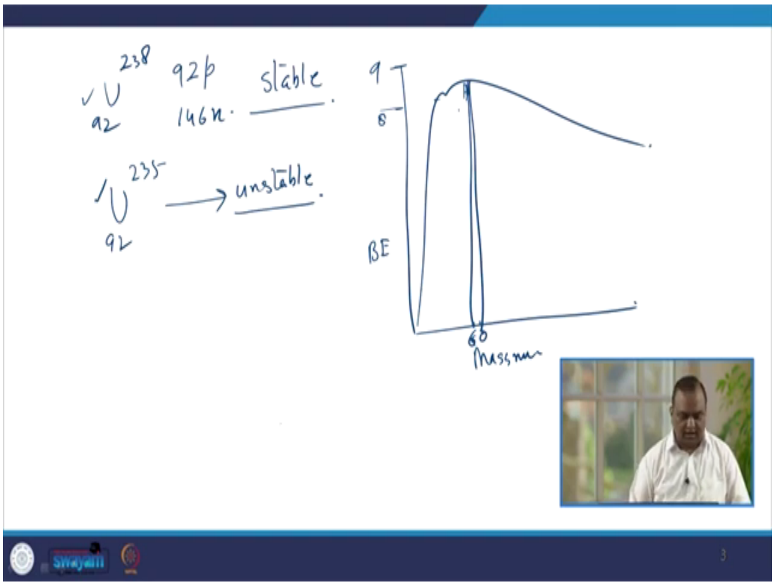

It is 92 protons and 146 neutrons and same 92 electrons. It is quite a stable right, but if you take uranium 235, it is quietly unstable, due to the fact that it has much lower binding energy than this one. Now, if you look at the if you are draw a curve for different mass number and this is negative binding energy. So, you will get a curve like this and iron is somewhere here and it is approximately 60 and this is 9 and this is 8. So, iron is somewhere here. So, it is the most stable that is why I said it is the most stable element right.

Now, when radioactive decay happens, I mean disintegration of disintegration happens, then there is a life for every substance right. We normally consider in the nuclear engineering, we are normally considered with the half life; half life of a substance.

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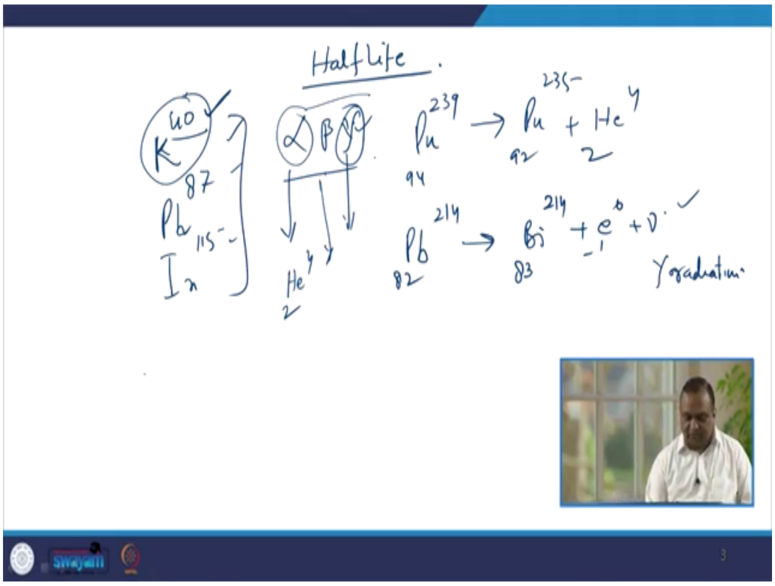

Half Life

K^{40}

Pb^{87}

In^{115}

α β γ

He^{4}_{2}

$Pu^{239}_{94} \rightarrow Pu^{235}_{92} + He^{4}_{2}$

$Pb^{214}_{82} \rightarrow Bi^{214}_{83} + e^{0}_{-1} + \nu$

γ radiation

So, half life is when the mass of the substances reduced to half, that is half life and you will find some of the isotopes which have low mass. For example, krypton 40; sorry potassium 40.

Potassium 40 is it is naturally radioactive, there is a normal perception that a heavy those who have elements those who have very high mass are radioactive, like some of the examples are like this potassium 40 or rubidium 87, this is also a radioactive. Indium 115, this is also radioactive.

And during radioactivity, alpha, beta and gamma rays, they come out of the substance. Alpha is I mean like helium, as you and you may be doing all these things. Now, gamma is a high frequency, low wavelength electromagnetic radiation. So, gamma penetration power of gamma is very high. Even a thin foil of say 1 mm thickness can you stop the alpha particles, but not the gamma particle, gamma rays. Gamma rays even can penetrate the ceiling of the house; I mean their penetration power or the energy level is quite high.

Now, I will give you an example of alpha decay. Suppose alpha decay is plutonium 239 94. If alpha decay is done, then plutonium 235, here 92 plus helium right. Beta decay suppose led 214 and 82, it causes this with 214 83 plus electrons 0 minus 1 plus neutrino and gamma radiation, this is for not for the beta, but this is for the gamma radiation. So, if you open a book on any book on the nuclear science, you will find a n number of equations how the, I mean radioactive decay takes place in different substances.

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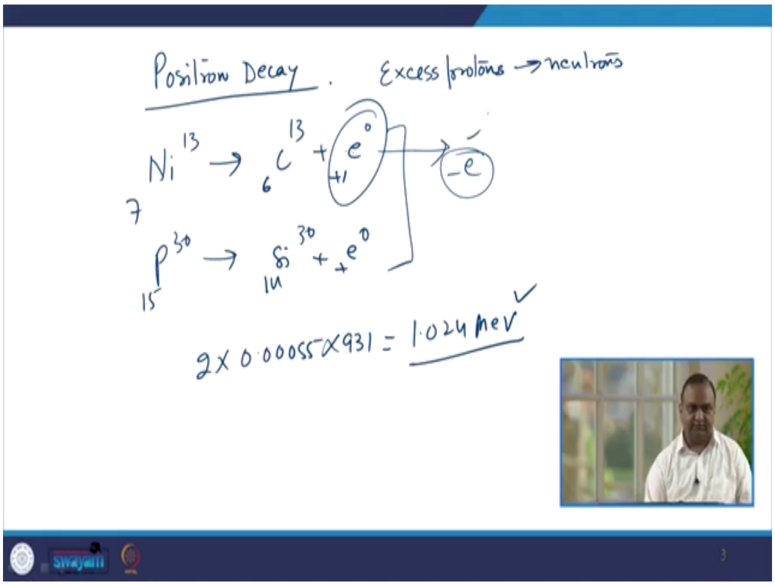

Positilron Decay. Excess protons → neutrons

$${}_{7}Ni^{13} \rightarrow {}_{6}C^{13} + \boxed{{}_{+1}e^{0}} \rightarrow \boxed{{}_{-}e}$$

$${}_{15}P^{30} \rightarrow {}_{14}Si^{30} + {}_{+}e^{0}$$

$$2 \times 0.00055 \times 931 = \underline{1.024\ MeV} \checkmark$$

There is a positron decay also, there is a that is very interesting positron decay. So, in this what happens? Excess protons converted into the neutrons right. For example, nickel 13 7 C 13 6 plus e 0 plus 1 or P 30 15 is convert to silicon 30 14 plus. So, these type of reaction also takes place. Sometimes inhalation process takes place. This positive electron it combines with them negative, it combines positron will combines with the electron and enormous an amount of energy is liberated that is known as inhalation.

And suppose, there are 2 electrons. So, 2 into their atomic mass unit is 00055 and 931, it is going to be 1.024 million electron volts are liberated when inhalation of electrons takes place. Now, we will discuss about the half life right.

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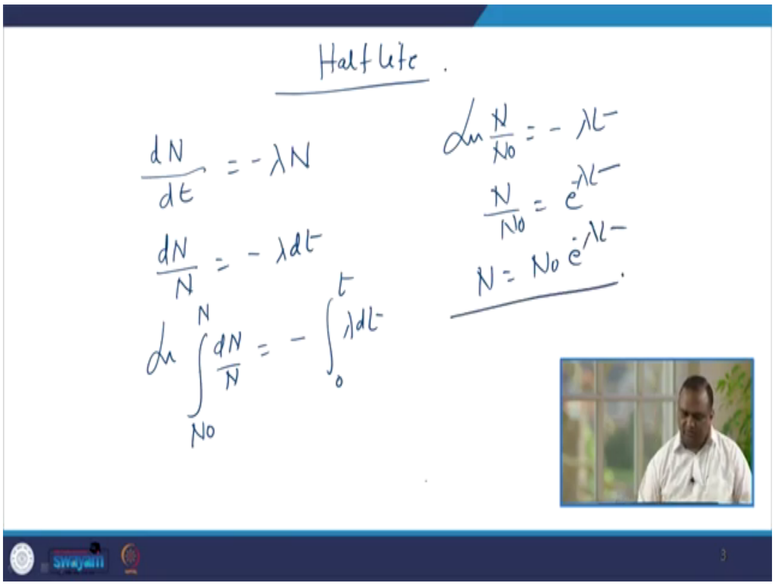

Half life .

$$\frac{dN}{dt} = -\lambda N$$

$$\frac{dN}{N} = -\lambda dt$$

$$\ln \int_{No}^{N} \frac{dN}{N} = -\int_{0}^{t} \lambda dt$$

$$\ln \frac{N}{No} = -\lambda t$$

$$\frac{N}{No} = e^{-\lambda t}$$

$$N = No\, e^{-\lambda t}$$

Now, radioactive decay of any substance is a first order reaction. So, dN by dt is equal to minus lambda N right. So, here we can take dN by N is equal to minus lambda dt or natural if we integrate both the sides. Integrate both the sides dN by N is equal to minus integrate lambda d t to 0 to t. This is initial and this is after time t.

We will get natural log N by N o is equal to minus lambda t or N by N o is equal to e to power minus lambda t or N is equal to N o e to power minus lambda t. Now, half life when N is when N is N o by 2 that is known as half life.

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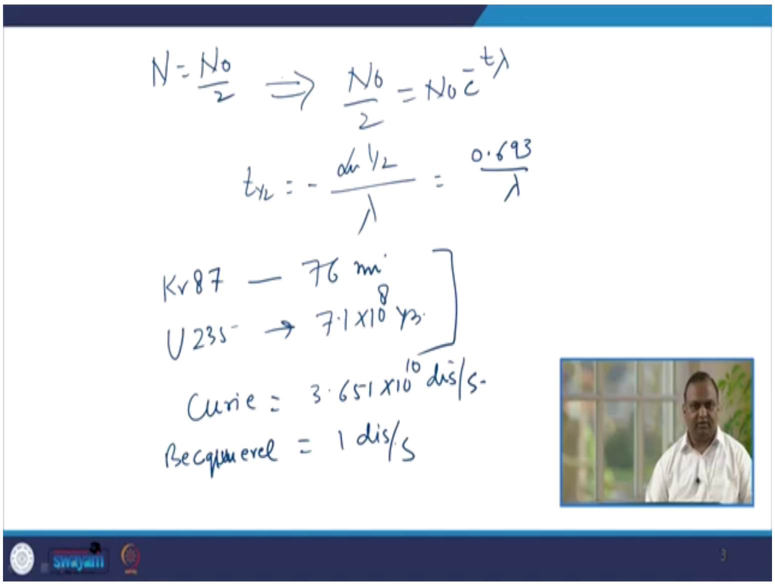

$N = \frac{N_0}{2} \Rightarrow \frac{N_0}{2} = N_0 e^{-t\lambda}$

$t_{1/2} = -\frac{\ln 1/2}{\lambda} = \frac{0.693}{\lambda}$

Kr87 — 76 mi

U235 → 7.1×10^{8} yrs.

Curie = 3.651×10^{10} dis/s.

Becquerel = 1 dis/s

So, when N is N o by 2, in that case N o by 2 is equal to N o e to power minus lambda t. So, t half is going to be equal to this is half; natural log of half minus natural log of half divided by lambda right and it is going to be equal to a 0.693 by lambda right. Now, in this case for example, krypton; if you take krypton 87. Half life is 76 minutes. If you take radioactive this uranium 235, half life is 71 point into 10 to power 8 years.

So, radioactivity is also having a unit. So, 1 unit is curie that is equal to 3.651 into 10 to power 10 disintegration per second and another unit is q u e r; Becquerel, it is equal to 1 disintegration per second.

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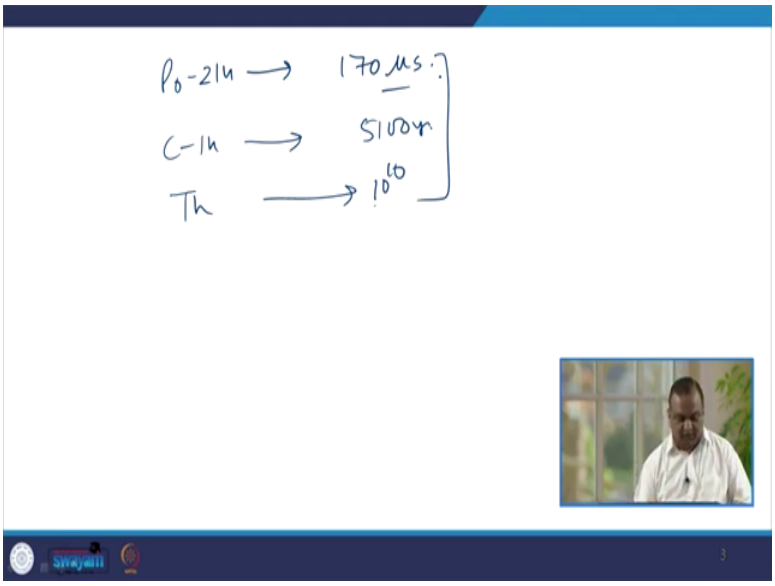

$Po\text{-}214 \rightarrow 170\ \mu s$.

$C\text{-}14 \rightarrow 5100\ yr$

$Th \rightarrow 10^{10}$

Now, similarly if you take the half life, it can be half life can be polonium 214 can be 170 micro seconds as well. Carbon 14 half life is 5100 years. Thorium, it goes up to 10 to power 10. So, it can vary from a few seconds or milliseconds or microseconds to millions of years. So, if you (Refer Time: 23:41) comes the average life.

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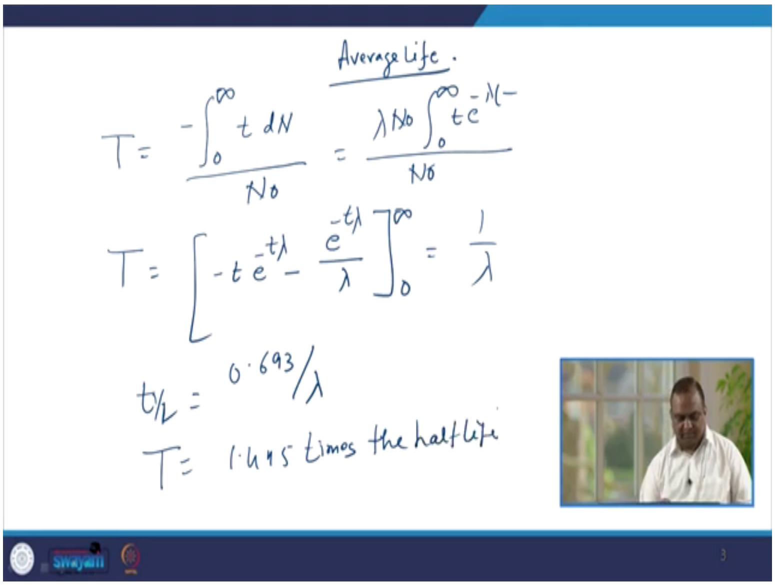

Average Life.

$$T = \frac{-\int_0^\infty t\, dN}{N_0} = \frac{\lambda N_0 \int_0^\infty t e^{-\lambda t}}{N_0}$$

$$T = \left[-t e^{-t\lambda} - \frac{e^{-t\lambda}}{\lambda} \right]_0^\infty = \frac{1}{\lambda}$$

$$t_{1/2} = 0.693/\lambda$$

T = 1.445 times the half life

What is the average life of a radioactive material? Average life. Now, in order to find the average life that is T, we will integrate 0 to infinity minus t dN by N o and this will give lambda N o 0 to infinity t e rise to power minus lambda t divided by N o. So, average life T is equal to if we integrate this and with this N o will be canceled out minus t e rise to power minus t lambda minus e raise to power minus t lambda divided by lambda 0 to infinity.

Now, if you are putting infinity here, at t they will become 0. Now, we are putting 0 and they are becoming equal to 1 by lambda. So, average life is 1 by lambda; half life is 0.693 by lambda. So, average life of any radioactive material is 1.445 times the half life. Now, for the power generation, a chain reaction is required; chain reaction, chain reaction.

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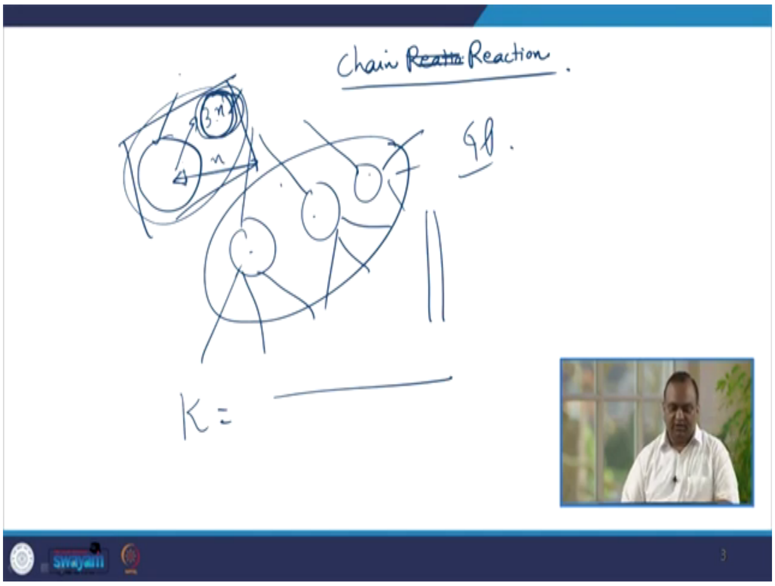

In chain reaction, what happens? For low energy neutron, strike the heavy nucleus right, then disintegration or decay of this nucleus takes place and enormous heat is liberated and at the same time, when suppose when neutron is striking this nucleus more; more than 1 neutron will leave this after disintegration, more than 1 neutron will leave this nucleus, suppose they are 3 neutrons, 1 neutron low velocity.

It is a high energy neutron, then it will penetrate. So, low energy neutron will go and strike the nucleus. Now, radioactive decay will take place which will contain 3 neutrons also and these 3 neutrons will again this strike another 3. This is how the chain reaction takes place. It will again strike again next 3 nucleus and in the next 3 nucleus again 3 neutrons and this chain will continue in GP. It is a fast reaction; it continues in GP and that is why there is a term K which is neutrons in any generation. This is first generation and so, this is second generation.

So, neutron in any generation divided by the neutron in previous generation; if it is more than 1, the chain will continue; otherwise, the chain will die out. And through this process and this is the basic of a nuclear power generation and nuclear power plants and in nuclear power plants for the reduction of the speed of the neutrals, moderators are provided. So, moderators are provided and these moderators, they retired or the reduce the kinetic energy of these neutrons. So, that proper fission or the chain reaction can take place.

So, further on this regarding the power generation in the nuclear power plant, we will discuss in the next lecture. This is all for today.

Thank you very much.