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**Lecture-56**
**Nuclear Radiation**

Welcome to another module of nuclear radiation. Now, we are very much aware about the severity and the dangers of these nuclear radiations. And sometimes these nuclear radiations, in different ways, they become the part and parcel of various chemical industries. Maybe attributed to some x-rays, maybe attributed to UV light, IR et cetera. So, there are different aspects associated with the chemical industries.

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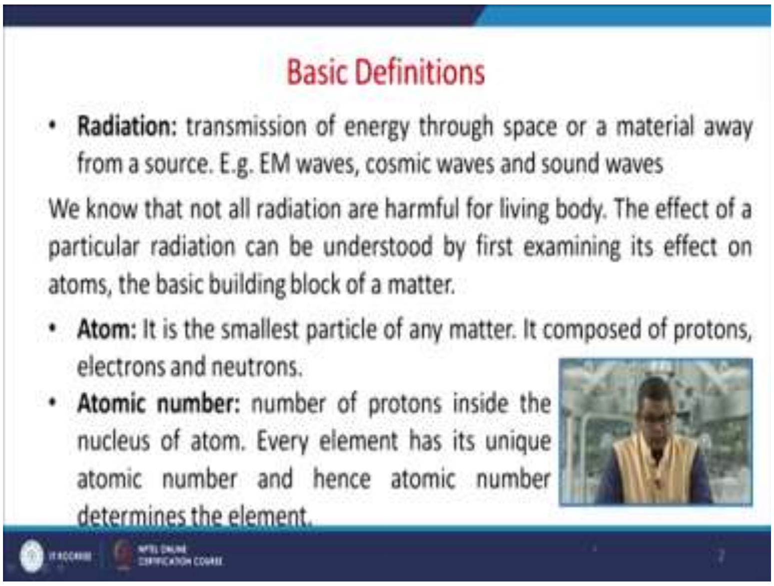


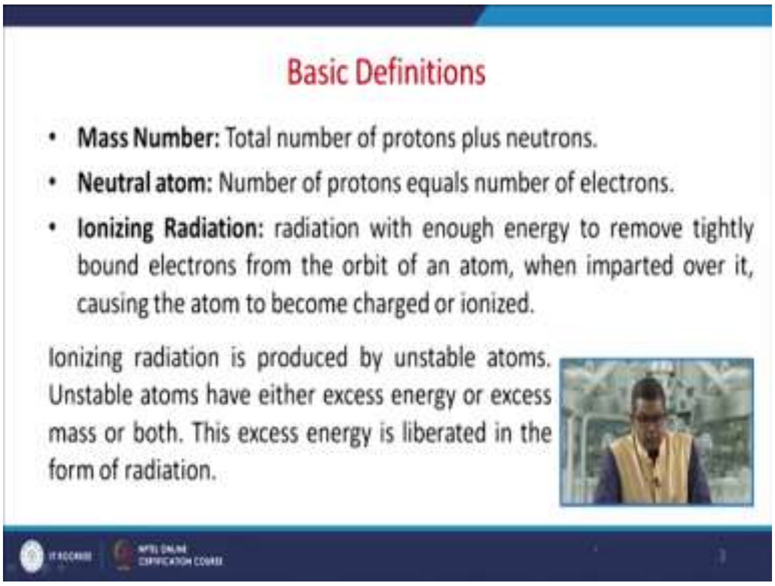

So, before we start with the gravity of this nuclear Radiation, let us have a look about the basic definition. So, as the start includes the Radiation term, so 1st thing is the Radiation. Now, what is radiation? Radiation is the transmission of energy through space or a material away from a source, like Electromagnetic waves, cosmic waves and sound waves. So, we know that all radiations are harmful for living body. The effect of a particular radiation can be understood by 1st examining its effect on atom, the basic building block of a particular matter.

Now atom, it is the smallest particle of any matter, it is composed of proton, electron and neutron. And atomic number, the number of protons inside the nucleus of atom, so, every element has its unique atomic number, hence atomic number determines the element. So, these are the some basic things which we must understand before we go further for this particular module. Apart from this, the mass number, that is the total number of protons plus neutrons in that particular element. Then neutral atom, the number of protons equals the number of electrons.

There is ionisation or ionising radiation. The radiation with enough energy to remove tightly bound electrons from the orbit of an atom. So, when imparted over it, causing the atom to become charged or ionised. So, ionising radiation is produced by unstable atoms and unstable atoms have either access energy or access mass or both. So, this access energy is liberated in the form of radiation.

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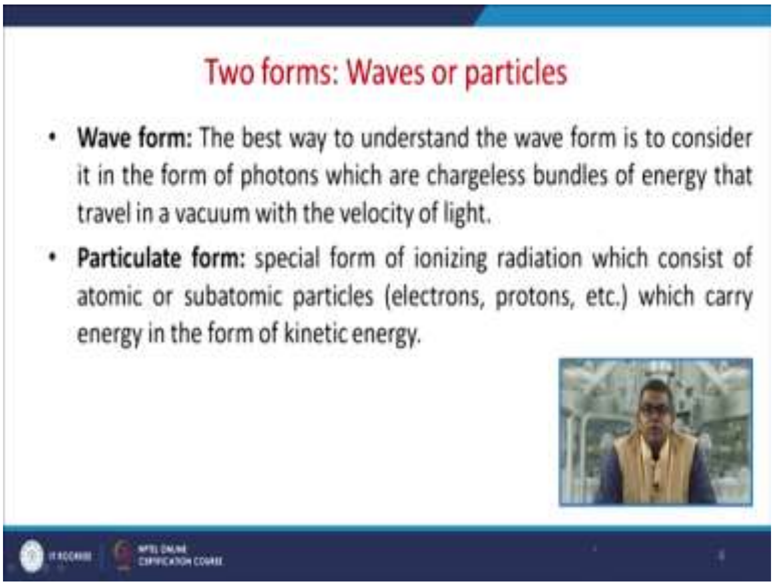

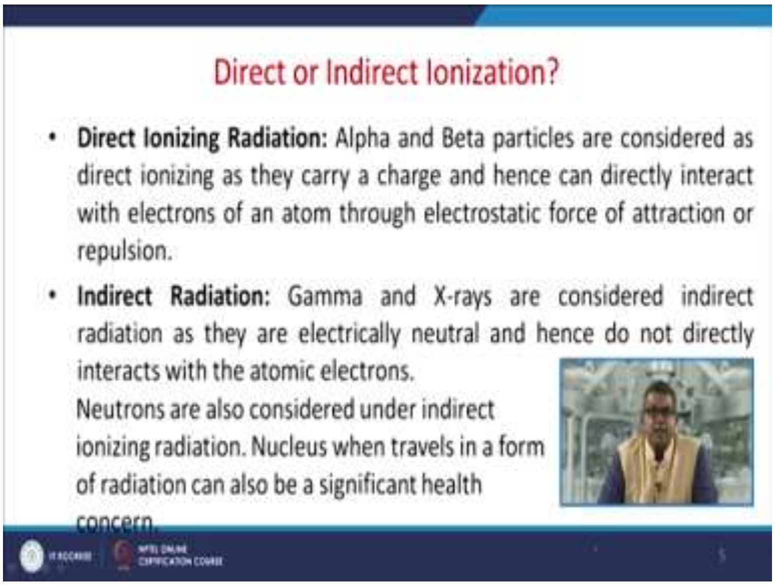


Now, there are 2 forms of things, waves or particles. So, waveform, the best way to understand the waveform is to consider it in the form of photons, which are charge less bundles of energy, that travel in a vacuum with the velocity of light. The particulate form, that is a special form of ionising radiation which consist of atomic or subatomic particles, that is electrons, protons, et cetera which carry the energy in the form of kinetic energy.

Let us take the question that direct or indirect ionisation, so direct ionising radiation, alpha and beta particles, they are considered as direct ionising, as they carry a charge and hence can directly interact with the electrons of an atom through electrostatic force of attraction or repulsion. The indirect radiation or ionisation, they are gamma and x-rays are considered indirect radiation as there electrically neutral and hence they do not directly interact with the atomic electrons. So the neutrons are also considered under the indirect ionising radiation. Nucleus when it travels in the form of radiation can also be a significant health concern.

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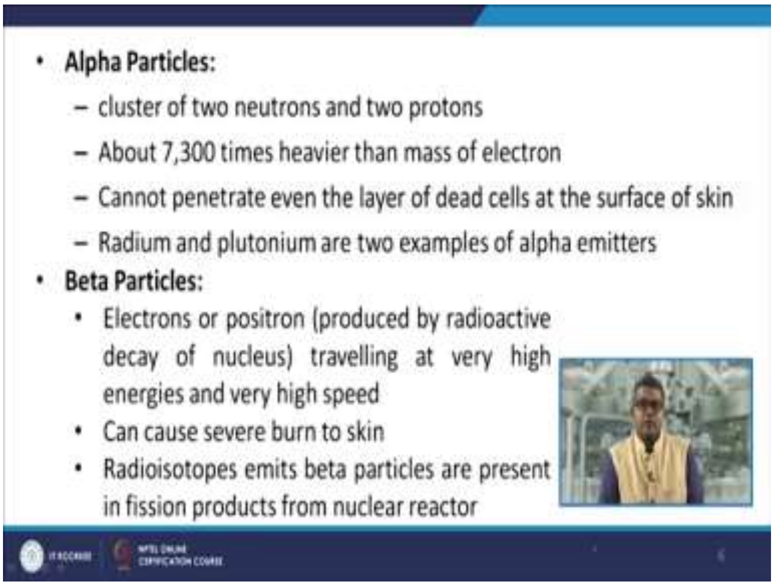


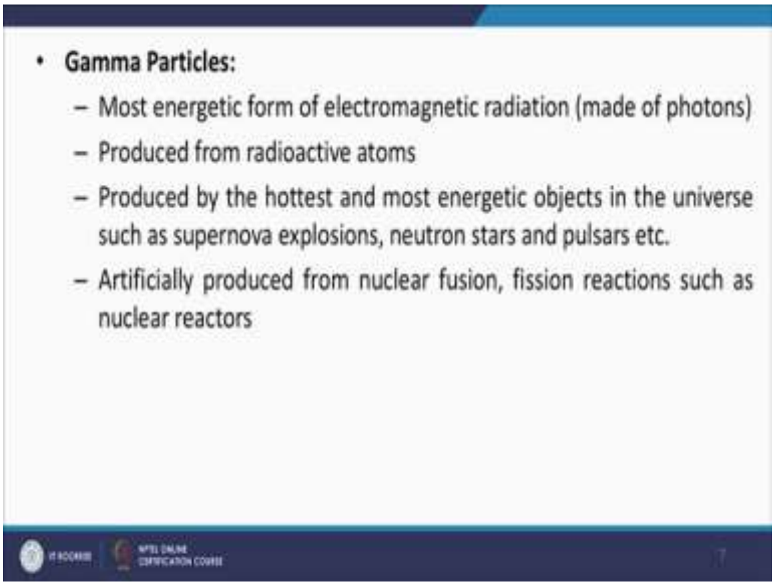


The alpha particles, they are the cluster of 2 neutrons and 2 protons. So, about 7300 times heavier than the mass of electron and they cannot penetrate even the layer of dead cells at the surface of skin. Radium and plutonium, they are the 2 examples of alpha emitters. Then there beta particles, the electrons or positrons, these positrons are produced by radioactive decay of nucleus, so these electrons are positrons travelling at a very high energies and very high-speed. They can cause severe burns to the skin. The radio isotopes emits beta particles are present in fission products from nuclear reactors.

There are certain gamma particles. They are the more energetic form of electromagnetic radiation, made of photons, produced from the radioactive atoms and are produced from the hottest and the most energetic object in the universe, such as supernova explosion, neutron stars and the pulsars, et cetera. They are artificially produced from the nuclear fission reaction, such as nuclear reactors.

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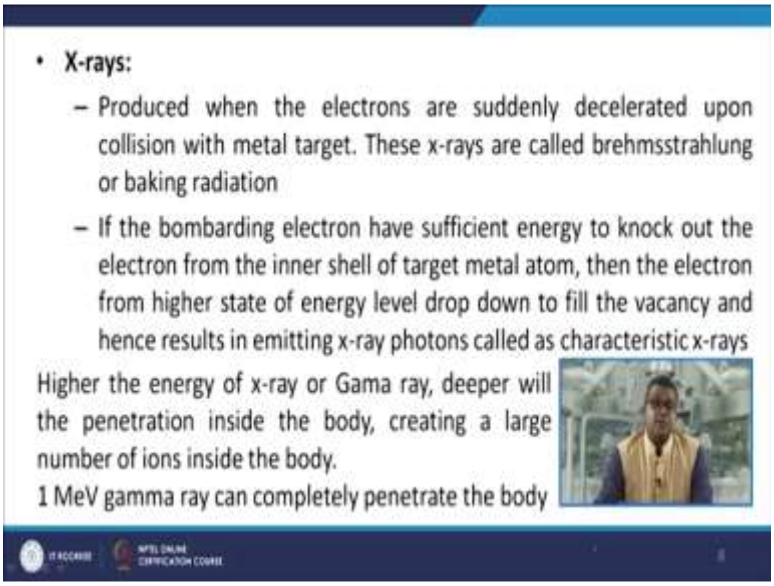


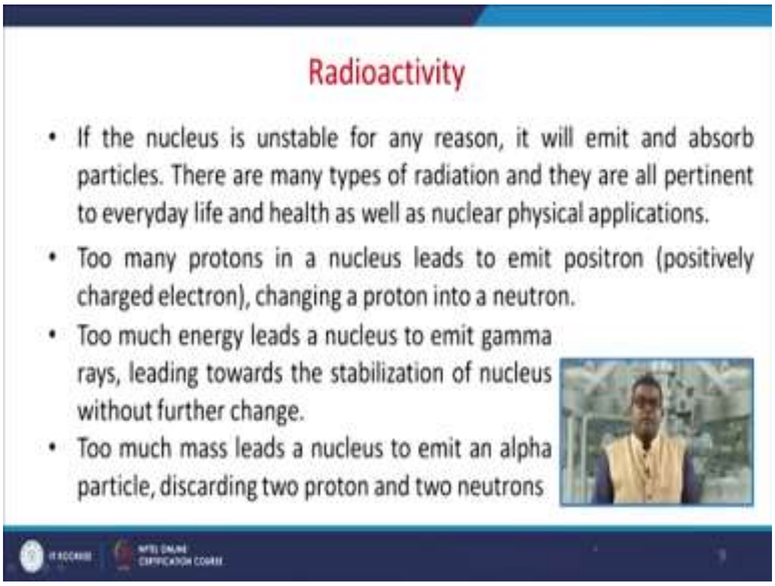

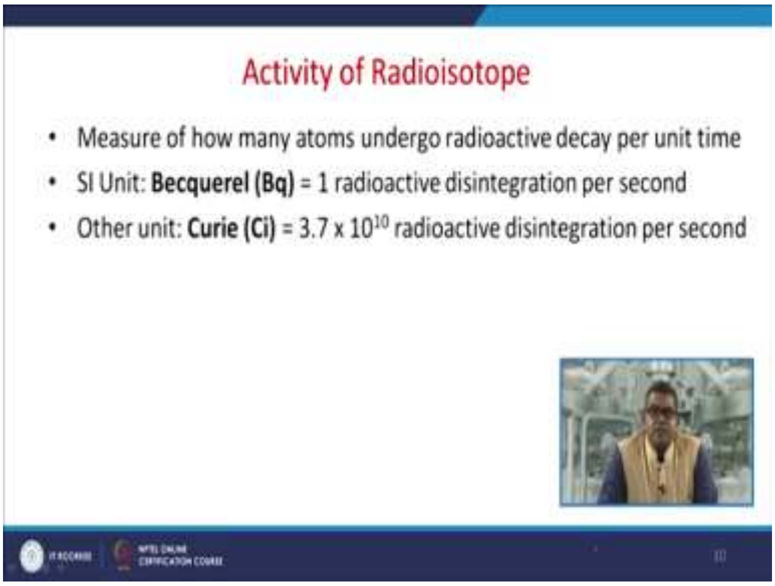


X-rays, very common in chemical engineering, they are produced when the electrons are suddenly decelerated upon collision with metal target. These x-rays are called the baking radiations. Now, if the bombarding of electrons have sufficient energy to knock out the electrons from the inertial of target metal atoms, then the electrons from higher state of energy level drops down to fill the vacancy and hence the result in emitting x-ray photons, that is called the characteristic of x-ray.

So, the higher the energy of x-ray all gamma ray, deeper will be the penetration inside the body and creating a large number of ions inside the body. So, one mega-electron volts gamma ray can completely penetrate the body. Now let us have a look about the radioactivity. So, if the nucleus is unstable for any reason, there are variety of reasons, so it will emit and absorb particles. And there are many types of radiation and they are pertinent to everyday life and health, as well as nuclear physical applications.

So, too many protons in a nucleus lead to emit positron, the positively charged electrons, changing a proton into a neutron. Now, too much of energy leads a nucleus to emit the gamma rays, now leading towards the stabilisation of nucleus without further change. And if you have too much of mass, leads the nucleus to emit an alpha particle, discarding 2 protons and 2 neutrons. Next thing is that activity of radio isotopes. So, this measures how many atoms undergo the radioactive decay per unit time. And the SI unit is (Bq), that is equal to the radioactive disintegration per second.

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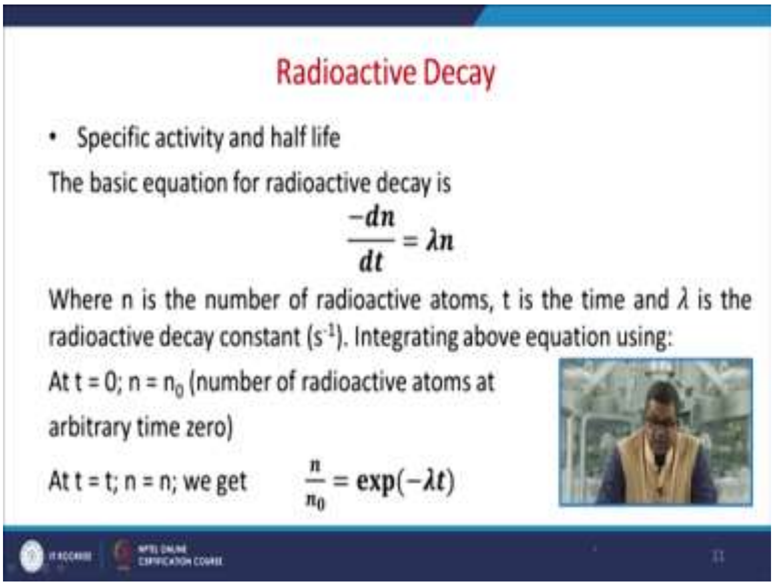


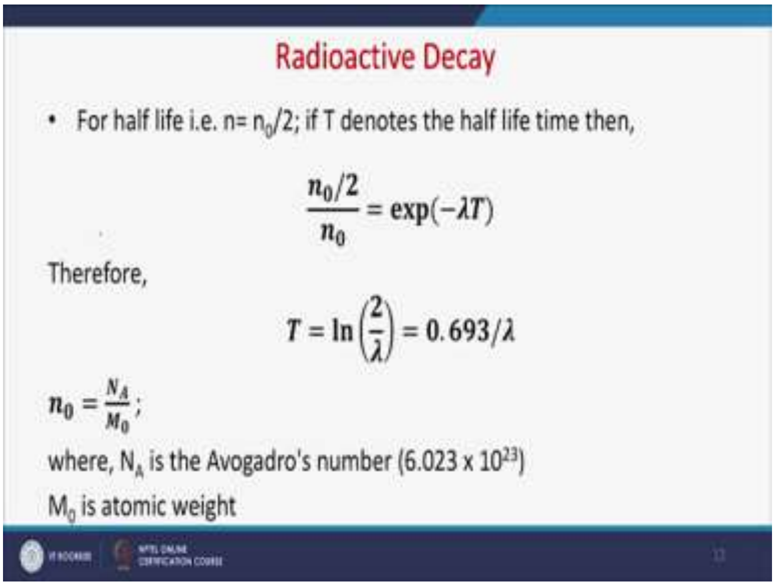


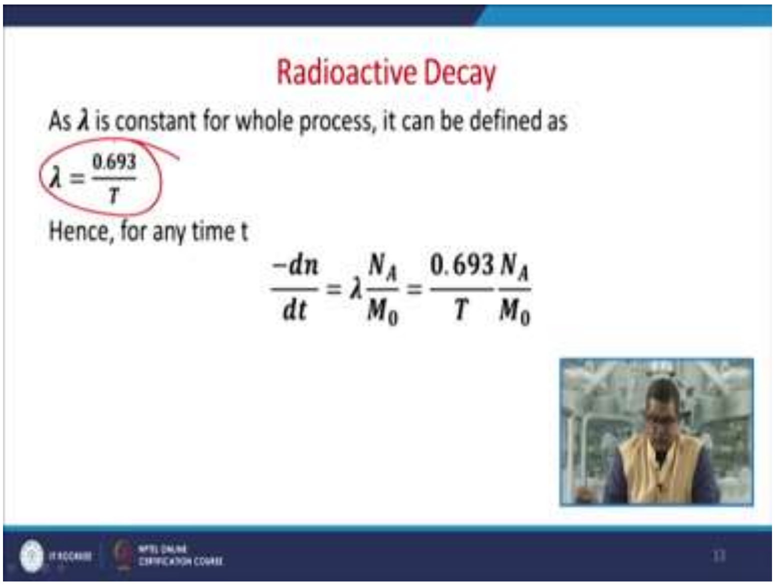

The other unit is the Curie, (Ci), that is equal to 3.7 into $10^{10}$ radioactive disintegrations per second. So, we have discussed the radioactive decay, so let us have a look about the radioactive decay, so the specific activity and half life of any radioactive material. The basic equation for the radiative decay is given by

$$\frac{-dn}{dt} = \lambda n$$

where n is the number of radioactive atoms and t is the time and lambda is the radioactive decay constant in the unit of second inverse. So, if we integrate the above equation using the time t equal to 0 and n equal to $n_0$, that is the number of radioactive atoms present at arbitrary time 0.

And t equal to t, n equal to n, we get

$$\frac{n}{n_0} = \exp(-\lambda t)$$

So, for half-life, that is n equal to $n_0$ upon 2 and T denotes the half life time, then

$$\frac{n_0/2}{n_0} = \exp(-\lambda T)$$

So, therefore

$$T = \ln\left(\frac{2}{\lambda}\right) = 0.693/\lambda$$

Where

$$n_0 = \frac{N_A}{M_0}$$

where $N_A$ is the Avogadro's number and 6.023 into 10 to the power 23 and $M_0$ is the atomic weight. So, as lambda is constant for entire process, so it can be defined as

$$\lambda = \frac{0.693}{T}$$

So, for anytime t

$$\frac{-dn}{dt} = \lambda \frac{N_A}{M_0} = \frac{0.693}{T}\frac{N_A}{M_0}$$

So, this represents the radioactive decay. The energy released during decay can be governed through Einstein equation

$$E = mc^2$$

Where C is the velocity of light, energy may also be calculated through decay equation, that is E is equal to change in the mass of atom into atomic mass unit amu and 1 amu is equal to 931 MeV.

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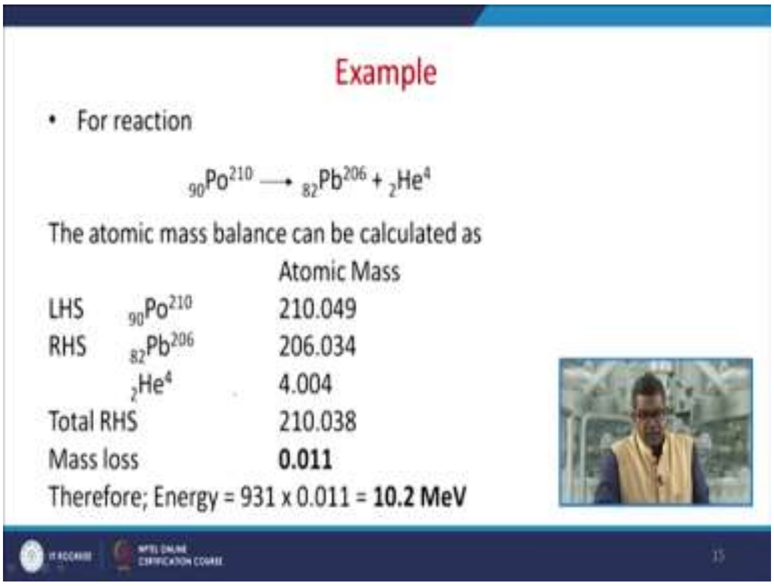


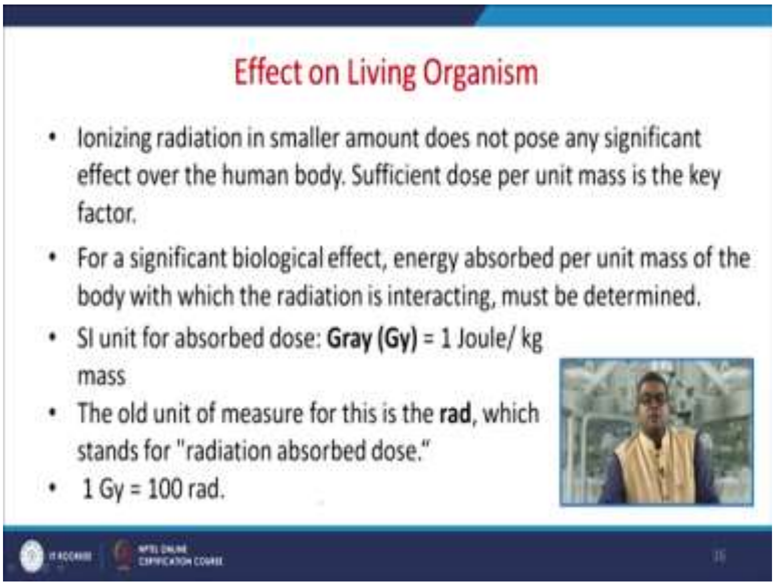

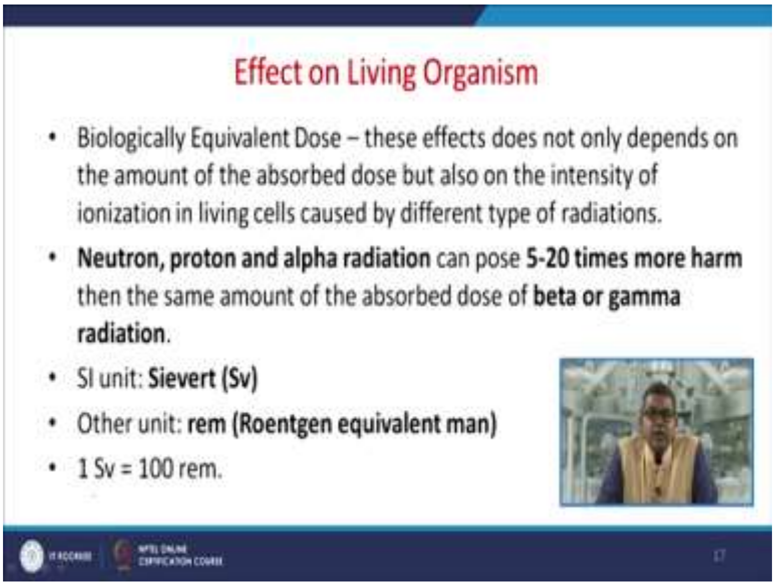


So, let us take an example of reactions, that is this

$$_{90}Po^{210} \qquad _{82}Pb^{206} + {_2}He^{4}$$

This atomic mass balance equation can be calculated by the left-hand side, this is the atomic mass 210. And the right-hand side 206 and this is having 4, helium. So, for right-hand side, it is 210.038 and the total mass loss is 0.011, therefore energy is equal to 931 into 0.011 is equal to 10.2 M EV. Now let us have a discussion about the effect on living organisms. Now, ionising radiation in a smaller amount does not pose any significant effect over the human body, now sufficient dose per unit mass is a key factor. That is dose versus the response.

So, for significant biological effect, energy absorbed per unit mass of the body with which the radiation is interacting, this must be determined. So, SI unit for the absorbed dose is equal to Gray (Gy) is equal to 1 joule per kilogram mass. The older unit, this is rad, which stands for radiation absorbed dose. And that is, there is a correlation factor between the grey and rad, this is equal to 1 Gy is equal to 100 rad. So, biological equivalent dose, now these effects does not only depend on the amount of the absorbed dose but also on the intensity of the ionisation in living cell caused by the different type of radiations.

So, neutron, proton and alpha radiation can pose 5 to 20 times more harm than the same amount of the absorbed dose of beta gamma radiation. So, the SI unit of this particular is Sievert Sv. The other unit is rem, that is Roentgen equivalent man. Now Roentgen, who invented the x-ray. So, 1Sv is equal to 100rem.

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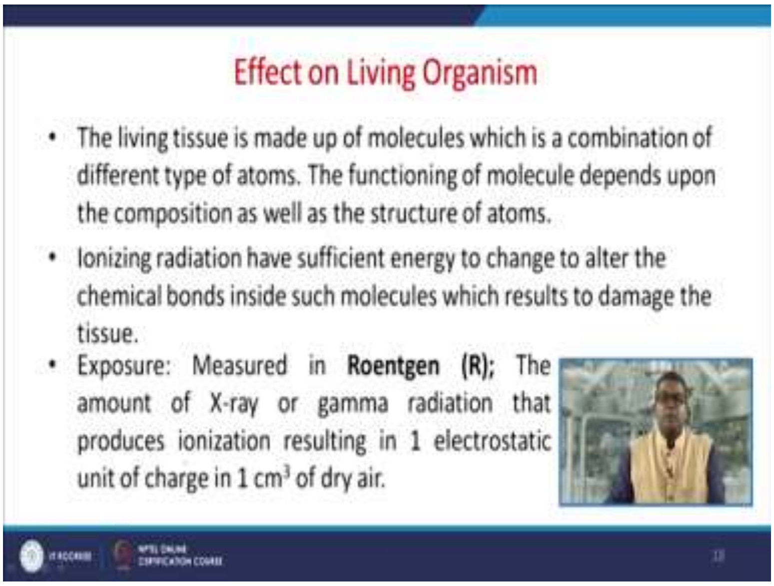


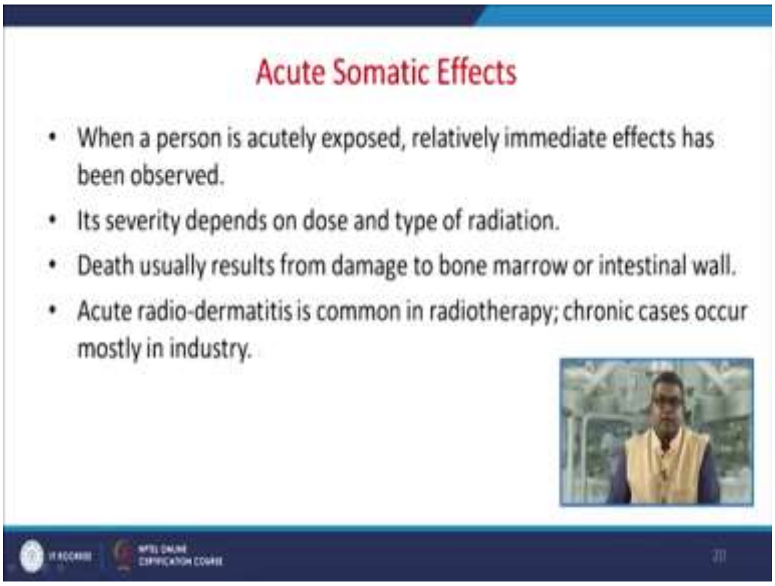


Now the living tissue is made up of molecules which is a combination of different types of atoms. The functioning of molecule depends on the composition as well as the structure of atoms. The ionising radiation has sufficient energy to change to alter the chemical bonds inside such molecules which results to damage the tissues. Exposure, this is measured in Roentgen R, the amount of x-ray or gamma radiation that produces ionisation resulting in one electrostatic unit of charge in 1 centimetre square of dry air.

Now if the ionising radiation emits the electron directly from the DNA or from the neighbouring molecules and disrupts the DNA, then it is called direct action. Now, if the electron strikes the ordinary water molecule which results to produce the free radical, the free radical interacts with other molecules at a very fast and may lead to disturb the crucial DNA molecule. Now, this is termed as indirect action. So, the fatal dose in this particular case is 600 R.

Now, there are certain acute asthmatic effect. So, when a person is actually exposed, the relative immediate effect has been observed. Now the severity depends on dose and type of radiation. Death usually results from damage to bone marrow or intestinal wall. The acute radio dermatitis is common in radiotherapy, chronic cases occur mostly in various industries.

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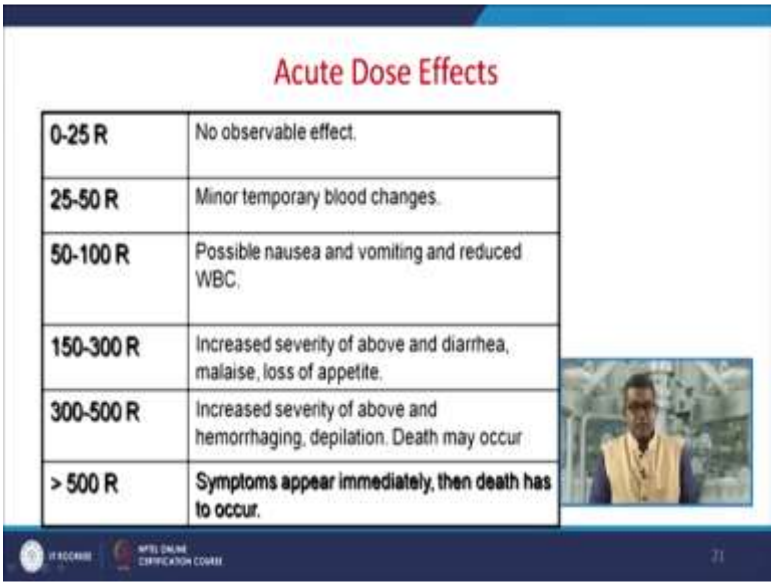


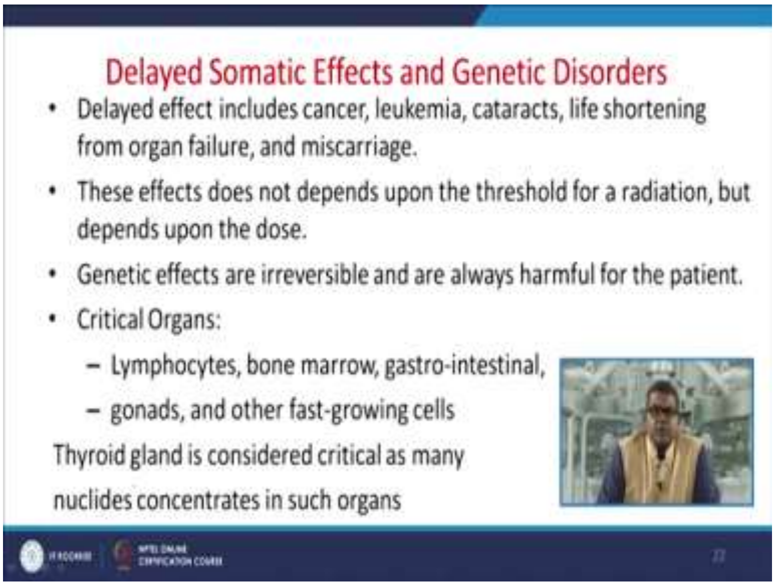


Now this is the table reflects the acute dose effects. So, if it is in the range of 0 to 25, no observable effect. If 25 to 50 R, minor temporary blood changes. 50 to 100 R, simple nausea and vomiting and reduced White Blood Cells. 150 to 300 R, increased severity of these type of activities and diarrhea, loss of appetite, et cetera. 300 to 500 R, increased severity of these above this thing, haemorrhaging, depletion, death may, sometimes death may occur. And if it is greater than 500 R, the symptoms appear immediately, then death has to occur. So, it is extremely dangerous.

Now, let us have a discussion about the delayed asthmatic effect and genetic disorders. So, delayed effect includes cancer, leukaemia, cataracts, life shortening from organ failure, miscarriage, et cetera. Now, these effects does not depend the threshold for radiation but depends upon the dosage. Genetic effects are irreversible and are always harmful for the patient. Now, there are critical against which are listed for this type of activity, that is lymphocytes, bone marrow, gastrointestinal, gonads and other fast-growing cells. Now, thyroid gland is considered critical as many nuclides concentrate in such particular gland.

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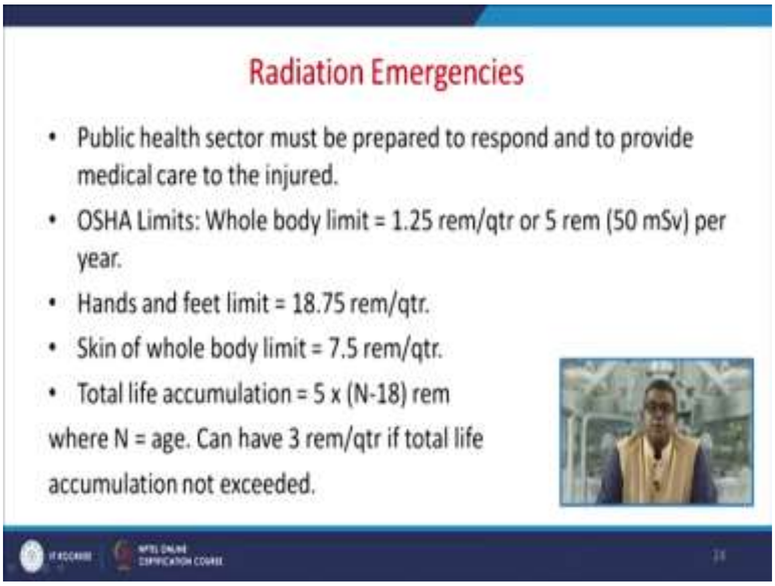


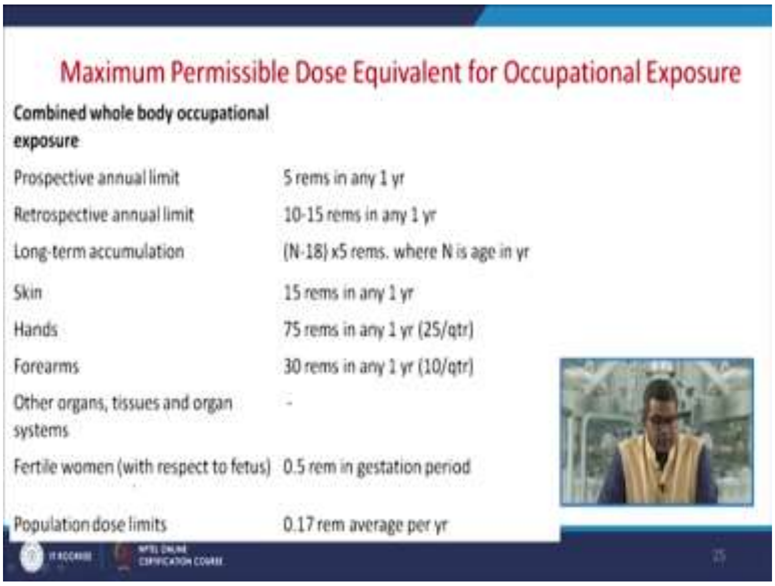

The radiation emergencies, the scale and type of radiological and nuclear emergencies may range from an isolated occupational or medical overexposure of a person to a major catastrophe with the global dimensions. Now, regardless the scale or a cause of the accident, there is a common denominator, that is human health. So, international health regulation in 2005 included Cisco radio nucleus hazards and countries should meet the core National capacities requirement for the response to radiation emergency.

The public health sector must be prepared to respond and to provide the medical care to the injured. There are OSHA limits for the whole body limit is 1.25 rem per quarter or 5 rem or 50 mSv per year. Hands and feet limit is 18.75 rem per quarter, scale of whole body limit is 7.5 rem per quarter,

total life accumulation = 5 X (N – 18) rem

where N is equal to H. So, one can have 3 rem per quarter if total life accumulation not exceeded. Now, this is, this particular table reflects the maximum permissible dose equivalent for occupational exposure.

Now here you are having combined whole-body occupational exposure, like prospective annual limit, 5 rems in any one year. The retrospective annual limit, 10 to 15 rems in any one year. Long-term accumulation, N -18 into 5 rems, where N is the age in year. Skin, 15 rems in any year, the hands, 75 rems in any one year, that is 25 per quarter. The forearms, 30 rems in any year, or you can say 10 per quarter, the fertile women, with respect to the fetus, 0.5 rem in the gestation period and population dose limits are 0.17 rem average per year.

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## Community Emergency Radiation

- Radiation above background (0.01-0.02 m rem/hr) signifies possible presence which must be monitored. Radiation above 2 milli rem/hr indicates potential hazard. Evacuate site until controlled.



## Nuclear Reactor Type: Principle types

- Gas-cooled reactors
  - Magnox reactor
  - Advanced gas cooled reactor
  - High temperature gas cooled reactor
- Light water reactors
  - Pressurized water reactor
  - Boiling water reactor
- Heavy water reactors
  - CANDU reactor
  - Steam generating reactor
- Fast breeder reactors



## Magnox Reactor

- Further vertical channels contain control rods (strong neutron absorbers) which can be inserted or withdrawn from the core to adjust the rate of the fission process and, therefore, the heat output.
- The whole assembly is cooled by blowing carbon dioxide gas past the fuel cans, which are specially designed to enhance heat transfer.

There are certain community emergency radiations. So, radiation above background that is 0.01 to 0.02 m rem per hour signifies the possible presence which must be monitored. So, radiation above 2 milli rem per hour indicates the potential hazard. And evacuate site until controlled is always advised under such scenario. Now, there are different type of nuclear reactors and the principal type of reactors we are going to discuss in this particular slide.

There are gas cooled reactors like Magnox reactor, advanced gas cooled reactor, high-temperature gas cooled reactor, there are certain heavy water reactor like CANDU reactor, steam generating reactor, there fast breeder reactors, there are certain lightweight reactors, those are pressurised water reactor and boiling water reactors. So, let us have a look about a Magnox reactor. The Magnox reactor was built in United Kingdom from 1956 to 1971 but have now been suspended or superseded with additional advanced systems.

Magnox Rector is named after the migration alloy used to encase the fuel, which has natural uranium metal. Fuel element consisting of fuel rod encased in Magnox can are loaded into the vertical channels in a core constructed of graphite blocks. This further channels, they contain the control rods like strong neutron absorbers which can be inserted or withdrawn from the core to adjust the rate of fission process and therefore the heat output. So, the whole assembly is cooled by blowing carbon dioxide gas passed into the fuel cans, which are specially designed to enhance the heat transfer.

Now, these hot gases then they are converted water to steam in steam generator. And early design used steel pressure vessel which was surrounded by a thick concrete radiation shield. So, in later design a dual purpose concrete pressure vessel and radiation shield was used. Now let us have a look about the advanced gas cooled reactor. So in order to improvise the cost effectiveness of a Magnox reactor, it was necessary to go for a higher temperature to achieve higher thermal efficiency and higher power density to reduce any kind of capital cost.

So, the entailed, the increase in cooling gas pressure and the changing from Magnox to stainless steel cladding and from uranium metal to uranium dioxide fuel. So, there is change the all aspects of, all key points of the Magnox reactor. Now, this in turn led to the need for an increase in the proportion of uranium 235 in the fuel. Now, the resulting design known as the advanced gas cooled reactor or AGR, now they still uses the graphite as the moderator and thus in the later part of Magnox design, the steam generators and gas circulators are placed within the combined concrete pressure vessel or radiation shield.

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Now, there are heavy water cooled and moderated reactors. The only design for having water moderated reactor in commercial use is CANDU. This is designed in Canada and subsequently exported to other countries. So, in this CANDU reactor, the enrichment, and reached uranium dioxide is held in zirconium alloy cans loaded into the horizontal zirconium alloy tubes. The fuel is cooled by pumping heavy water through the tubes under very high pressure to prevent any kind of boiling. And then to a steam generator to raise steam from ordinary water. So, this is also known as natural or light water in the normal way.

The necessary additional moderation is achieved by merging the zirconium alloy tubes in an unpressurised container,that is called the Calendria that is containing more heavy water. Control is affected by inserting and withdrawing the cadmium rods from Calendria and the whole assembly is contained inside the concrete shield and containment vessel. There are certain fast reactors, so as of today the commercially successful reactor system or the thermal reactors using a slow thermal neutrons to maintain the fusion chain in the chain reaction in uranium 235 fuel.

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## Fast Reactors

- Consequently, when these atoms absorb an extra neutron, their nuclei do not split but are converted into another element, Plutonium.
- Plutonium is fissile and some of it is consumed in situ, while some remains in the spent fuel together with unused $U_{235}$.

## Fast Reactors

- This is the fast reactor in which the neutrons are unmoderated, hence the term "fast".
- The physics of this type of reactor dictates a core with a high fissile concentration, typically around 20%, and made of Plutonium.
- In order to make it breed, the active core is surrounded by material (largely $U_{238}$) left over from the thermal reactor enrichment process.

## Fast Reactors

- This material is referred to as fertile, because it converts to fissile material when irradiated during operation of the reactor.
- Due to the absence of a moderator, and the high fissile content of the core, heat removal requires the use of a high conductivity coolant, such as liquid sodium.
- Sodium circulated through the core heats a secondary loop of sodium coolant, which then heats water in a steam generator to raise steam.

Now, even with the enrichment level used in the fuel for such reactors for the largest number of atom present, they are uranium 238, which are not feasible. No, consequently when these atoms absorb an extra neutron, their nuclei do not split but are converted into another element called plutonium. The, plutonium is fissile and some of it is consumed in situ, while some remain in the spent fuel together with the unused uranium 235. Now, these components can be separated from the fission product waste and recycle to reduce the consumption of uranium in thermal reactor by say up to 40 percent.

Although clearly thermal reactor still require a substantial net feed of natural uranium. So, it is possible however to design a reactor with the overall produce is more fissile material in the form of plutonium than it consumes. So, that is why they are called the fast reactors. So, this is the 1st reactor in which the neutrons are unmoderated and hence the term is fast. The physics of this type of reactor dictates core with a high fissile concentration, typically around 20 percent and made of plutonium. Now in order to make it breed, the active core is surrounded by the material that is largely uranium 235, left over from the thermal reactor enrichment process.

Now, the material is referred as fertile because it converts the fissile material irradiated during operation of the reactor. So due to the absence of any kind of moderator and high fissile content of the core, heat removal requires the use of a high conductivity coolant, such as liquid sodium, et cetera. So, sodium circulated through the core heats the secondary loop of sodium coolant which then heats water in a particular steam generator to raise the steam. And this steam is being used for the power generation.

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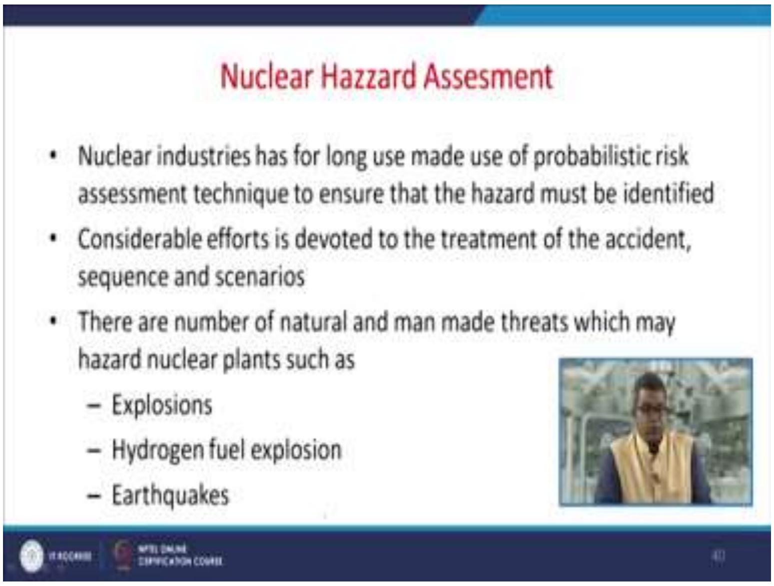

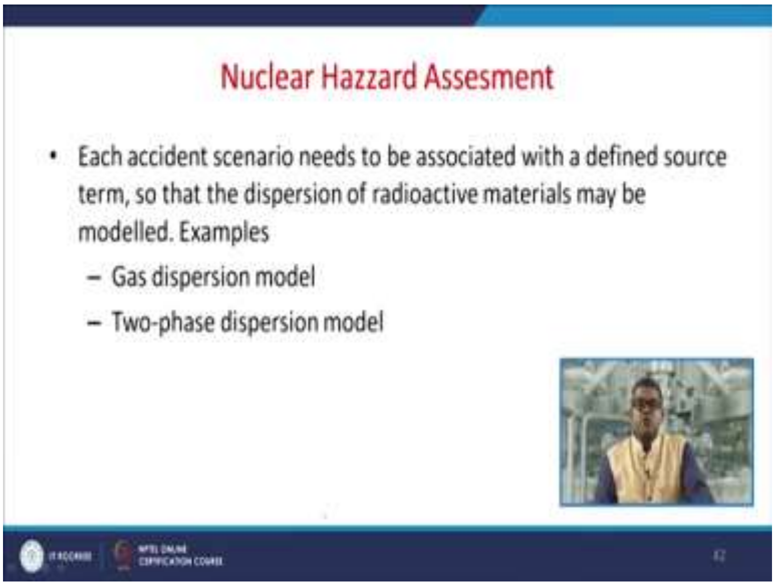


Now let us take the assessment of nuclear hazard. So, nuclear industry for long made use of probabilistic risk assessment technique to ensure that the hazard must be identified. Considerable efforts is devoted to the treatment of the accident, sequence and scenarios. And there are number of natural and man-made threats which may hazard nuclear plants such as explosions, hydrogen fuel explosion, earthquakes, et cetera. So, when sufficient information is not available, the resort maybe had to the use of expert judgement. And it may be used to obtain the failure and even threats or the formulation of accident sequences.

So, as nuclear power plant operates under the computer-controlled, quality assurance of software and hardware is essential. While doing inventory analysis and Fault tree analysis for conducting probabilistic risk assessment, the estimation of human error is very important. Now, each accident scenario needs to be associated with the defined source term, so that the dispersion of radioactive material may be modelled. Like example gas dispersion model, two-faced desperation model.

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## Recommendations

- All aspects of the design and operation of nuclear power plant need to be carried out to high standards. This leads to the generation of system of quality assurance standards.
- High quality inspection is an essential part in nuclear industries. These includes acoustic emission monitoring, ultrasonic and leak detection methods, risk based inspection etc.
- One of the most important inspection technique is fracture mechanics.
- Seismic quantification is also an essential part of regular inspection to judge the threats of earthquakes.



## Recommendations

- Nuclear industries always explore in details the factors like, ageing of instrument, and residual or remaining life assessment.



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Now, there may be certain recommendations may be attributed to this particular aspect. Like all aspects of the design and operation of nuclear power plant need to be carried out to high standards. This leads to the generation of system of quality assurance standards. High quality inspection is an integral part or an essential part of nuclear industries. These include caustic emission monitoring, ultrasonic and leak detection methods, risk-based inspection, et cetera. One of the most important inspection techniques is the fracture mechanics.

Seismic quantification is also an essential part of the regular inspection to judge the threats of any kind of earthquakes. Now, nuclear industries, they always explored in details the factors like ageing of instrument, residual or remaining life assessment, et cetera, there are so many. So, in this particular module, we have discussed about the nuclear radiation and in different modules we will discuss one of the most worst nuclear disasters that is called the Chernobyl. So, if you wish to have the further reading, then the series of references are listed in this particular slide, thank you very much.