Sun: The sun is the ultimate source of energy for all processes going on the earth. It produces light energy, which differentiates our nights and days, and also the other forms of energies such as wind energy, water energy, energy of fossil fuels and energy in our food.

Sun influences life on the earth in the following ways:

1. Sun sustains life on the earth: Plants prepare food in the presence of sunlight by a process called photosynthesis. All animals and humans depend on these plants for their food. It is this food, which provides sustenance to the animals and humans on the earth. Sun also provides light and warmth on the earth. Moderate temperature on the earth is one of the factors, which helped the life to originate and sustain on this planet.
2. Sun controls wind and water cycles on the earth: The heat energy from the sun warms up the air and causes its flow. The heat energy of the sun radiation causes water to evaporate from water bodies on the earth. The evaporated water returns to the earth in the form of rain or snowfall. Water is one of the most essential factors, which helped the life to originate and sustain on the earth.
3. Solar energy is stored in fossil fuels: Fossil fuels such as coal, petroleum and natural gas are formed from the biomass of dead plants and trees deep inside the earth in the absence of air. Thus, energy of fossil fuels is the solar energy stored in plants and trees millions of years ago.
4. Solar energy can be utilized for heating and cooking: Nowadays solar energy is also utilized for heating and cooking with the help of solar cookers, solar heaters etc. Solar cells are used for generating electricity directly from the sunlight.

<u>What powers the sun?</u>

Sun is a direct and huge source of energy. It is very hot and the temperature on its surface is about 5500-6000 k. In the core of the sun, temperature is about 15 million degrees. In earlier times, it is believed that the sun was a huge ball of burning coal. The astronomical observations show that mass of the sun is about 10^{30} kg or 10^{27} ton. Had the sun been a ball of coal, this mass would take only about 5000 years to burn off. But, we have the evidence to prove that the sun has been burning for much longer than that.

Scientists have recorded the presence of 600 million years old fossils. These fossils could not have existed without the sun. Thus, it is certain that the sun has existed for more than 600 million years. In fact, the sun has been burning for about 5 billion years.

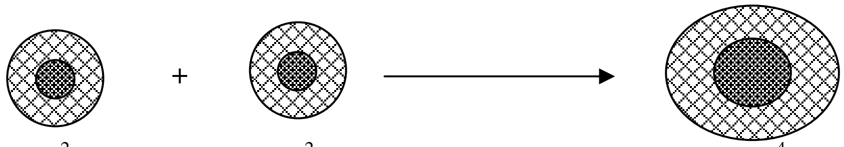
Around 1920, scientists found that each element when white-hot emits light of a particular wavelength (or a particular colour). Thus, it became possible to detect the presence of any element in a substance by studying the wavelengths of light emitted by it when hot. This method called spectral analysis can be employed even from a distance.

By studying the light coming from the sun, scientists concluded that sun consists of hydrogen (92%), helium (7.8%) and other elements (0.2%). Thus, the sun is mainly made up of hydrogen. Therefore, it was suggested that the energy of the sun must come from hydrogen. Hydrogen gas burns in the presence of oxygen to produce heat. However, the heat energy liberated during combustion (burning) of hydrogen is not that large so as to account for the energy given out by the sun. Thus, it was felt that in the sun, hydrogen produces energy by some other processes.

In 1939, a German scientist Hans Bethe of Cornell University discovered the actual process responsible for the generation of energy in the sun. He suggested that the process of nuclear fusion could be the only source of solar energy. This process involves a fusion (joining together) of lighter nuclei to form a slightly heavier nucleus. This process also releases a lot of energy. The sun has an almost inexhaustible amount of light elements, such as hydrogen and helium, which together constitute about 98% of the mass of the sun. Bethe suggested that four nuclei of hydrogen fuse together to form the nucleus of a helium atom. The mass of the nucleus of the helium atom so formed is less than the combined mass of the four nuclei of hydrogen atoms. The rest of the mass is converted into energy in accordance with Einstein's mass-energy equivalence relation. This energy is released in the form of solar radiation. Thus the process of nuclear fusion of hydrogen nuclei is the source of energy of the sun. The basic reaction by which energy is generated by the sun is:

4 H He + 2e + energy
Hydrogen **Helium** **Positron**

The sun radiates about 3.8×10^{26} J of energy per second.



+ Energy

$_1H^2$ Hydrogen atom, $_1H^2$ Hydrogen atom, $_2He^4$ Helium atom, Heat & Light Energy.

<u>Composition of Solar Energy:</u> A detailed observation of the solar spectrum revealed that the sunlight radiated by the sun consists of three main types of waves viz., ultra violet rays, visible light and infra red rays with different limits of wavelengths as explained under:

i) <u>Ultra violet rays:</u> These include the radiations having wavelength less than that of the visible light i-e less than 0.4 μ or 4 x 10^{-7} m. These rays are invisible to us, but produce fluorescence in certain substances (like Barium cyanide plate or Zinc cyanide plate). These are harmful for living organisms and cause various severe diseases.

ii) <u>Visible light:-</u> The visible portion of the solar spectrum consists of seven colours ranging from violet to red (VIBGYOR). It is visible to our eyes and its wavelength varies from 0.4μ (4×10^{-7}m) in violet to0.7 μ (7×10^{-7}m) in red. The middle colour of this spectrum is green with a wavelength of 0.53 μ. (0.53×10^{-7}m).

iii) <u>Infra-red rays:-</u> It includes invisible rays having a larger wavelength than that of the visible red light i-e greater than 0.7 microns (7×10^{-7}m). These radiations are invisible to naked eyes. These contain about one third of the total energy radiated by the sun. It is only due to infra red rays that earth, water and air gets heated.

Structure of atom:

An atom consists of small positively charged nucleus. Nucleus in an atom is surrounded by electrons, which revolve around it in nearly circular paths called orbits.

The electron is the lightest of the atomic particles and has a mass of 9.1×10^{-31}. Electrons and the nucleus are held together by electrostatic forces of attraction: electrical charges of opposite sign attract each other.

Nucleus of an atom consists of subatomic particles such as proton and neutron. The particles, which reside in the nucleus of an atom, are called nucleons. So, neutrons and protons are called nucleons.

Almost the entire mass of an atom is concentrated in its nucleus. The nucleus of an atom consists of neutrons and protons; so, the mass of an atom is equal to the total mass of the neutrons and proton in its nucleus

Atom as a whole is electrically neutral, so, in an atom, number of protons inside its nucleus and the number of electrons surrounding the nucleus are equal.

The diameter of an atom is about 10^{-10} m, where as the size of the nucleus is of the order of 10^{-15} m. The coulomb force of attraction between opposite charges binds the electrons to the nucleus.

Atomic number:

The number of protons in the nucleus of an atom is called atomic number of that atom. It is represented by the symbol Z. it was given by Mosley in 1913. According to him, the atomic number is equal to the nuclear charge. The charge on the nucleus of an atom is equal to the number of protons inside it s nucleus. That is,

Atomic number (Z) = Number of protons (P) inside the nucleus

An atom has no net charge on it. So in an atom, the total number of electrons is equal to the number of protons inside its nucleus. Thus in an atom, the total number of electrons is equal to the atomic number of that element.

Mass Number:

Mass number of an atom is denoted by A. The mass number of an atom is equal to the sum of the number of protons (P) and the number of neutrons (N) in its nucleus. Thus,

Mass number (A) = Number of protons (P) + Number of neutrons (N)

Or $A = P + N$

The number of protons (P) inside the nucleus of an atom is equal to the atomic number (Z) of that element. So,

Mass number (A) = Atomic number (Z) + Number of neutrons (N)

Or $A = Z + N$

Isotopes:

Atoms of the same element having the same atomic number but different mass numbers are called isotopes of that element.

All isotopes of an element have the same atomic number., so all isotopes of an element should contain the same number of protons inside their nuclei. Also different isotopes of an element have different mass numbers. So the number of neutrons in the nuclei of all the isotopes of an element is different. so, isotopes may also be defined as: -

The atoms of the same element which have the same number of protons but different number of neutrons inside their nuclei are called isotopes of that element.

Isotope of an element is described by writing their mass numbers as superscript on the top left side of the symbol. Their atomic numbers are written as subscript at the left side bottom of the symbol. For example, isotope of an element X is described as:

X or X

Isotope of hydrogen:

There are three isotopes of hydrogen, represented by the symbols:

H H and H

They all contain just one proton (and hence one electron) but different number of neutrons. The first isotope H is the ordinary hydrogen atom which contain no neutron. The second isotope H is called deuterium and it contains one neutron. The third isotope H is called tritium which has two neutrons. These isotopes are used in nuclear fusion.

<u>Isotopes of Uranium:</u>

The two isotopes of uranium of special importance in nuclear fission are: -

U and U

Which are respectively called Uranium-238 (or U-238) and uranium – 235 (or U-235). Both isotopes have the same number (92) of protons in the nucleus of each uranium atom. The isotope U-238 contains 238 – 92 = 146 neutrons while the isotope U – 235 – 92 = 143 neutrons in each nucleus. U – 235 is an unstable isotope and can easily be fissioned (or broken).

<u>Nuclear Reaction:-</u> A reaction in which the nucleus of an atom undergoes a change to form a new atom and releases an enormous amount of energy is called as nuclear energy.

The first nuclear reaction was performed successfully by Lord Rutherford of England in 1919. He bombarded nitrogen gas by fast-moving alpha particles. An alpha particle is just the helium nucleus (He), obtained by removing the electrons from a helium atom. Rutherford found that when an alpha particle (He) strikes a nitrogen nucleus (N), an isotope of oxygen (O) and a proton (H) were formed. (A proton is just the nucleus of an ordinary hydrogen atom; it is obtained by the removal of the electron from a hydrogen atom). This reaction is represented as: -

$$N + N \longrightarrow O + H$$

In 1934, Enrico Fermi of U.S.A and his coworkers performed an important nuclear reaction (called nuclear fission) that liberated a lot of energy. They bombarded uranium- 235 atoms with neutrons and found that, as a result of a nuclear reaction the uranium atoms break up into two lighter atoms of barium and krypton, with the emission of neutrons and liberation of enormous energy. This reaction is represented as:

$$U + n \longrightarrow Ba + Kr + 3\ n + \text{(enormous energy)}$$

In an exothermic nuclear reaction (I,e a nuclear reaction in which energy is liberated), it is found that the sum of the masses of the product nuclei is less than that of the masses of the interacting nuclei. The difference (m) between the two is known as the mass defect. This extra mass is converted into energy in accordance with Einstein's mass-energy equivalence relation.

$$E = mc^2$$

Where E is the energy equivalent of mass m. and c is the speed of light in vacuum. Since the value of c is high ($c = 3 \times 10^8\ ms^{-1}$) and that of c^2 even higher , a small mass defect m can produce a large amount of energy.

Nuclear reaction is of two main types:

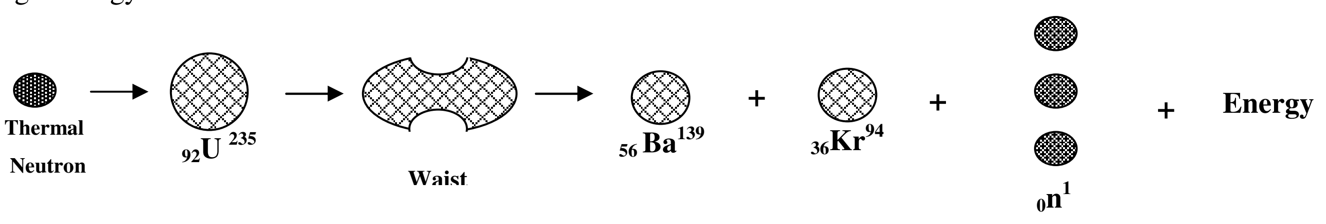
i. Nuclear Fission reaction.

ii. Nuclear Fusion reaction.

i). <u>Nuclear Fission reaction:</u>

This type of nuclear reaction was first of all reported by Otto Hahn in 1938. He stated that when an unstable heavy nucleus is bombarded with slow speed thermal neutrons, it splits into two small stable nuclei liberates an enormous amount of heat and light energy.

When uranium 235 atoms are bombard with slow moving thermal neutrons, it breaks up into two small stable nuclei of Barium and Krypton. The process also produces three neutrons and an enormous amount of heat energy and light energy. The reaction involved is shown as under:



$$U + n \longrightarrow Ba + Kr + 3\ n + \text{Large amount of energy}$$

In all nuclear fission reactions, a small quantity of matter is lot I,e the total mass of all the fission products is less than the total mass of the reactants. This lost matter gets converted into energy, which is released in any nuclear fission reaction. The energy (E) obtained due to loss of matter of mass m is given by the famous Einstein's equation.

$$E = mc^2$$

<u>Calculation of energy released during Fission:</u>

When one atom of uranium-235 is fissioned, a total of 200 Mev of energy is released out in the form of heat and light. Since one gram atom of uranium 235 contains 6.023×10^{23} atoms. Thus

Energy released by one Uranium atom = 200 Mev.

and 235gm of ${}_{92}U^{235}$ contains = 6.023×10^{23} atoms of ${}_{92}U^{235}$

$\therefore$ Energy released by 235gms of ${}_{92}U^{235}$ = $6.023\times10^{23} \times 200$ Mev.

But 1 Mev = 1.6×10^{-13} Joules

Thus Energy released = $6.023 \times 10^{23} \times 200 \times 1.6 \times 10^{-13}$ Joules

= 1.927×10^{-13} Joules

Also 1 Calorie = 4.186 Joules

$$= \frac{1.927 \times 10^{-13}}{4.186} \text{ Calories.}$$

$$= 4.6 \times 10^{12} \text{ Calories.}$$

We know that Heat of combustion of coal = 8×10^{9} Cal. Per M. ton.

Thus 4.6×10^{-13} calories of Heat energy will be produced by the combustion of

$$= \frac{4.6 \times 10^{-12} \text{ Calories.}}{8 \times 10^{9} \text{ Cal / M. ton.}}$$

= 575 Metric Tons.

Thus, energy released by the fission of just 235 grams of Uranium 235 is equal to that produced by 575 metric tons of coal, which gives a clear indication of the enormous amount of heat energy released in the fission process.

<u>Types Of Nuclear Fission:-</u> A nuclear fission reaction is of two main types viz.

1) <u>Uncontrolled Fission or Explosive Fission Reaction:</u>

In this type of fission reaction, the fission of the nuclear fuel (Uranium-235) is deliberately allowed to continue in an uncontrolled fashion by allowing all the secondary neutrons to proceed, until the reaction results in an explosion. [10^{20} Uranium atoms in 1 minute]. The atomic bomb is based on the principle of uncontrolled fission U-235 or any other fissionable material.

In uncontrolled nuclear fission all the neutrons released cause further fissions and the multiplying effect continues leading to an explosion.

Let us assume that each neutron takes one second to cause further fission and the first fission takes place at r = 0 s. In this fission, three neutrons are produced. Thus, at the end of one second i,e for t = 1 s, fission of 3 more U nuclei takes place and 9 neutrons are released. Thus, at the end of two seconds i,e for t = 2 s, fission of 9 (=3^2) more nuclei takes place and 27 neutrons are released. Thus, at the end of three seconds I,e t = 3s, fission of 27 (= 3^3) more nuclei takes place and 81 neutrons are released. Thus, at the end of four seconds I,e, for t = 4 s, fission of 81 (= 3^4)
more nuclei takes place and 243 neutrons are released. Then

No. of U nuclei that would Fission in 1 min in an uncontrolled Fission $= 1 + 3 + 3^2 + 3^3 + \text{---------} + 3^{60} \approx 10^{28}$

Thus, in one minute 10^{28} nuclei of uranium – 235 undergo fission. One gram of uranium –235 contains about 2.5 x 10^{21} nuclei. Thus, in an uncontrolled fission all the nuclei present in 1 g of uranium –235 would undergo fission in just a fraction of minute leading to a sudden outburst of energy.

2) <u>Controlled Fission or Critical Fission Reaction:</u>

In this type of fission reaction, the fission of the nuclear fuel (Uranium 235) is controlled by retaining a limited number of neutrons, so that the number of uranium atoms fissioned remains constant with time. A nuclear fission reaction in which only one neutron from a fission is able to cause another fission and the remaining extra neutrons are removed without causing any fission is called a controlled nuclear fission.

In controlled fission of uranium – 235 two of the released neutrons are removed and only one neutron is allowed to cause further fission. As a result, only one uranium – 235 nucleus undergoes fission in one second. Thus.

No. of U nuclei that would Fission in 1 min in a controlled fission = 1 per second x 1 min = 1 per second x 60 second = 60

Thus, in a controlled nuclear fission, the number of neutrons available for fission remains constant. As a result, in a controlled fission reaction energy is released at a steady rate and remains manageable.

Nuclear Chain Reaction: A reaction in which the species which starts the reaction is also produced so that the reaction continues to take place is called chain reaction.

Thus, a chain reaction once started continues to proceed until one of the reactants is completely used up or the species, which propagates the reaction, is destroyed.

Following are the typical examples of chain reaction:

1. Chemical chain reaction: Reaction between hydrogen and chlorine in diffused sunlight is a chemical chain reaction. This reaction involves the following steps.

$$Cl_2 \longrightarrow 2Cl$$

Active species to start the chain reaction

$$H_2 + Cl \longrightarrow HCl + H$$

Active species to propagate the chain

$$Cl_2 + H \longrightarrow HCl + Cl$$

Active species to propagate the chain

$$H + Cl \longrightarrow HCl$$

Chain stops here

2. Nuclear chain reaction: - Fission of uranium – 235 nucleus with slow neutrons is a nuclear chain reaction. The fission of uranium – 235 nucleus is started by a slow neutron.

When uranium – 235 is bombarded with slow neutrons, a nucleus of uranium – 235 absorbs one neutron. This compound nucleus then splits into two lighter nuclei, releasing three neutrons and a large amount of energy.

$$U + n \longrightarrow Ba + Kr + 3\ n + \text{large amount of energy}$$

These three neutrons then further split 3 more uranium nuclei, and 9 more neutrons are given out. These 9 neutrons will further produce 27 more neutrons. Thus, the reaction proceeds in a chain-like manner until the fuel (U) is completely consumed or the neutrons are removed.

If the nuclear chain reaction is not controlled, it would lead to an explosion due to sudden outburst of energy. A controlled fission produces energy steadily which can be used for generating electricity.

The chain reaction involving the fission of uranium – 235 (U) is illustrated below:

What is an atom bomb?

A device based on the uncontrolled nuclear fission is called an atom bomb. Thus, atom bomb is based on the principle of uncontrolled nuclear fission of a fissionable material such as uranium- 235. When a uranium – 235 nucleus is hit by a slow neutron, it splits into barium and krypton nuclei and 3 neutrons and a large amount of heat are released. These 3 neutrons cause fission of three more uranium – 235 nuclei releasing 9 neutrons. These 9 neutrons cause fission of nine more uranium – 235 nuclei releasing 27 neutrons. These neutrons cause further fission finally leading to an explosion. In actual practice, it has been found that explosion due to uncontrolled fission is possible only if the quantity of uranium – 235 is more than a certain minimum quantity. Such a minimum quantity of the fissionable material is called its critical mass. Thus, an atomic bomb should contain a certain minimum quantity of uranium – 235 (or any other fissionable material). In its safety position, an atom bomb consists of several thousand small samples of uranium – 235. At the time of explosion, these samples come together and the neutrons from radium – beryllium (Ra – Be) source strike the large sample to explosion of atomic bomb.

The atomic explosion causes a rise in temperature, pressure and violent and intense blast of visible, X – rays and γ - radiations, which cause large scale damage and destruction.

i). <u>Nuclear Fusion reaction:</u>

This type of nuclear reaction was first of all reported by Hans Bethe in 1939. The word ‘fusion’ means ‘to combine together’. So, nuclear fusion means combining together of two or more nuclei to form a single nucleus. Thus, a process in which two lighter nuclei fuse (combine) together to form a stable heavier nucleus with a simultaneous release of a very large amount of energy is called nuclear fusion. The energy produced in a fusion reaction is much higher than that produced in a nuclear fission reaction.

Nuclear fusion takes place only at very high temperature, about 4 – 15 million degrees ($4 \times 10^6\ ^0C - 15 \times 10^6\ ^0C$). That is why nuclear fusion is also called thermonuclear reaction.

Fusion reaction in the sun:

In 1939, Prop. Hans A. Bethe postulated that the source of the sun's energy is the fusion of hydrogen in the interior of the sun. Hydrogen nuclei in the interior of the sun under very high pressure and temperature (about 4 – 15 million degrees) fuse together to form helium nuclei. The basic fusion reaction by which energy is generated in the sun and other stars is:

$$4\ H \longrightarrow He \quad + \quad 2\ e \quad + \ Energy$$

The sun radiates about 3.8×10^{26} J of energy per second. It has been estimated that the mass loss due to the fusion reaction in the sun is about 4.2×10^6 tons per second. Sun suffers a mass loss at the rate of 4.2×10^6 tons per second, (mass of the sun: 2×10^{27} tons).

Fusion reaction in the laboratory:

The proton – proton fusion requires very high temperature, pressure and densities. This fusion reaction takes place in the sun because of the extremely high density of protons in the sun's interior. In laboratories, fusion reaction is studied by using an isotope of hydrogen called deuterium (H). It is very difficult to produce such a high temperature and pressure in the laboratories. However, scientists have succeeded in producing such high temperature and pressure for a very short interval ($\approx 10^{-9}$ s to 10^{-11} s).

Therefore, as of today it is not possible to carry out the nuclear fusion reactions in the laboratory except for a very short interval ~ 10 –9 s to 10 –11 s. Thus, in a laboratory, fusion takes place for a very short interval and then stops and the energy is released in short bursts.

What is hydrogen bomb?

A practical application of the nuclear fusion is a hydrogen bomb or fusion bomb.

Hydrogen bomb is based on the principle of nuclear fusion of hydrogen. Nuclear fusion requires very high temperature. In a hydrogen bomb, the high temperature needed for nuclear fusion is obtained by the nuclear fission of uranium – 235 (U).

In a hydrogen bomb, a mixture containing all the three isotopes of hydrogen, H, H, H, in a suitable amounts is coupled with an atomic bomb based on fission. The fission reaction is triggered and the heat produced in the fission reaction, triggers the fusion of hydrogen, releasing huge amount of energy. A hydrogen bomb is about one thousand times more powerful than an atomic bomb.

Difference between Nuclear fission and fusion:

Nuclear Fission	**Nuclear Fusion**
1) It involves breaking of a heavy nucleus into two light nuclei.	1) It involves binding of two lighter nuclei into a heavy nucleus.
2) It is carried out by the bombardment of thermal neutrons over a heavy nucleus	2) It is carried out by heating two lighter nuclei upto an extreme temperature.
3) It is a chain reaction.	3) It is not a chain reaction.
4) It is a controlled process.	4) It is an uncontrolled process
5) It produces an enormous amount of energy.	5) It produces more energy than nuclear fission.

Difference between chemical reactions and nuclear reactions:

CHEMICAL REACTIONS	NUCLEAR REACTIONS
1. No new atoms or elements are formed in a chemical reaction.	1. New nuclei or particles are formed in a nuclear reaction.
2. Only the outermost electrons take part in a chemical reaction, the nuclei of the atoms remaining unchanged.	2. Nuclei of atoms undergo a change in composition in a nuclear reaction.
3. In an exothermic chemical reaction, usually a small amount of energy is liberated.	3. In an exothermic nuclear reaction, a large amount of energy is liberated.
4. The liberation of energy is due to the sharing or transfer of the outer most electron of atoms.	4. The liberation of energy is due to mass defect.
5. In a chemical reaction, the total number of atoms is conserved.	5. In a nuclear reaction both the total atomic and mass numbers are conserved.
6. Chemical reactions are usually affected by changes in temperature and pressure.	6. Nuclear reaction are not affected by changes in temperature and pressure.
7. Some chemical reactions are reversible.	7. Nuclear reactions are irreversible.
8. Different isotopes of an element have the same chemical reaction because they have the same number of electrons in their atoms.	8. Different isotopes of an element have different nuclear reactions because they have a different number of neutrons in the nuclei of their atoms.

Occurrence of Uranium: In nature, uranium mainly occurs in two isotopes uranium 235 and uranium 238. Uranium 238 is more abundant in nature and thus most of the uranium occurring in nature is in the form of uranium 238 isotope (99.3%) and a very minute percentage (0.7 %) of uranium 235 isotope. However traces of uranium 234 are also found in nature. Thus natural uranium is first processed so as to increase percentage of uranium 235 isotope in it and the process being referred to as enrichment. Hence uranium fuel is oftenly called as enriched fuel or enriched ore.

Enrichment of Uranium: Naturally – occurring uranium has about o.7% of uranium – 235 and the restU-238.Thus in the naturally-occurring uranium for every 140 atoms of U-238 does not undergo fission. Uranium-235 undergoes fission when bombarded with slow neutrons. For a nuclear fission reaction, the concentration of uranium – 235 (U) should be 2.5% to 3%. So, the naturally occurring uranium cannot be used as a nuclear fuel as such. To make the naturally occurring uranium fir for its use in a nuclear reactor, the concentration of uranium- 235 in it should be increased to about 2.5 – 3%.

The process of increasing the percentage of uranium – 235 (U) in a sample of uranium to 2.5 – 3% is called enrichment of uranium or enrichment of nuclear fuel.

Nuclear Reactor: A nuclear reactor is a specially designed scientific apparatus in which the nuclear fission process is carried out in the form of a self sustaining chain reaction. This apparatus was constructed mainly for carrying out controlled fission of a radioactive substance like uranium 235 and to use efficiently the intense amount of heat energy released in the reaction. The first nuclear reactor was installed and successfully operated by Enrico Fermi in USA in the year 1942. A typical nuclear reactor consists of the following parts:

1) **Nuclear Fuel:** The fissionable material which is used in a nuclear reaction to produce an enormous amount of energy is called as nuclear fuel. The chief fuel used is enriched uranium-235, which contains about 2% to 3% of easily fissionable uranium-235 isotope and remaining of uranium-238 isotope. The powdered uranium dioxide containing 2.5 – 3% uranium – 235 is cast into pellets. These pellets are placed in tubes which are then sealed at both the ends. Several of these tubes are then assembled to form a bundle. Each bundle is then covered with a sheath made of zirconium alloy. This unit is called a fuel element or fuel rod.

2) **Reactor core:** It is the portion of a nuclear reactor in which the nuclear fuel is inserted and the process of controlled fission is carried out to produce a large amount of heat energy. It is made up of steel. In the reactor core, a large number of fuel rods are placed parallel to each within equal space between them.

3) **Moderator:** The neutrons released during fission of uranium – 235 nuclei move very fast (up to 42000 Km/s). these fast neutrons cannot cause fission of uranium- 235. To make use of these neutrons for causing further fission, these should be slowed down to about 3 Km/s. Fast moving neutrons can be slowed down by placing a substance called moderator around the fuel rods in the core. A substance which slows down fast neutrons released during the fission reaction is called a moderator.

The most common moderators used in a nuclear reactor are graphite and heavy water. Graphite is a form of carbon, and heavy water (D_2O) is a compound of oxygen and heavy hydrogen called deuterium. Small pieces of uranium are spread throughout the moderator. When a slow neutron strikes a uranium atom, it initiates the fission process, I,e splitting of the uranium atom with the production of more fast moving neutrons. These neutrons travel through the material of the moderator and lose their kinetic energy (and hence their speed) due to repeated collisions with the nuclei of the moderator. The slowed-down neutrons cause fission in other uranium atoms and a chain reaction is set up. Typically, a reactor uses 200 to 300 tons of heavy water as moderator.

4) **Controlling Rods:** A nuclear reactor core is also provided with Cadmium or Boron rods. These rods slow down the rate of the fission reaction by removing excess of neutrons present in the nuclear core and make the reaction critical or controlled. When the control rods are moved inwards, more neutrons are absorbed by these rods and the number of neutrons in the reactor decreases. This decreases the rate of fission. On the other hand, when the control rods are pulled out, lesser neutrons are absorbed by these rods and the number of neutrons in the reactor increases. This increases the rate of fission. The control rods are so positioned that on an average only one neutron is available for further fission per nucleus fissioned.

5) **Coolant:** The substance which is circulated through a nuclear reactor, so as to take out the enormous amount of heat energy and utilise it move efficiently. The commonly used coolants are metal sodium, water and carbon dioxide. The coolant is circulated through the pipes welded into the reactor vessel. The coolant transfers heat to the water in heat exchanger for producing steam.

6) **Radiation shield or protective screen:** The fission of uranium nuclei releases a lot of energy in the form of heat, light and gamma radiations. These radiations are harmful to animal and plant life. So, a protective screen made of special concrete about three meters thick is built around the reactor. It stops the escape of these harmful radiations.

7) **Generator:** The enormous heat energy carried by the coolant is used to produce steam that can run a turbine, which in turn can operate a generator to produce electricity. The heat energy of a steam is first converted into mechanical energy of the turbine which, in turn is converted into electrical energy by the electric generator.

Working of a nuclear reactor:

First of all the control rods (made of cadmium or boron) are completely inserted inside the moderator (graphite or heavy water). Then the rods made of enriched uranium are inserted between control rods. The control rods, when fully inserted, absorbs all the neutrons released by U – 235 nuclei and thus prevent the sudden initiation of the chain reaction.

To start the reactor, the control rods are gradually drawn out from the core of the moderator, with a substantial portion of the rods still inside the moderator, at this stage, the neutrons released by a uranium nucleus strike the nuclei of other uranium atoms and cause fission., the control rods are gradually drawn out further until the exact number of neutrons required for a controlled chain reaction are retained, the excess neutrons having been absorbed by the portion of the control rods inside the core of he moderator. At this stage, the controlled chain reactor supplies heat energy at a steady rate and the reactor is said to have become critical.

The coolant (liquid sodium) is now pumped into the reactor with the help of a pump. The coolant continuously flows through the pipes embedded in the reactor and takes away the intense heat produced in the fission reaction. This extremely hot sodium is made to pass through the coils of the heat exchanger into which water is pumped. The water takes away the heat from the hot sodium and is converted into steam. This steam is then passed into the turbine and is used to rotate its blades. The blades are coupled to a shaft, which rotates the coil in an electric generator, thus producing electricity. The unused steam is passed through a condenser where it is condensed to form water and this water is again circulated in the heat exchanger.

Criticality of a nuclear reactor:

In a nuclear reactor uranium – 235 is fissioned with the help of slow neutrons. The rate of fission depends upon the number of neutrons in the reactor. When the number of nuclei undergoing fission per unit time becomes constant, the fission reaction proceeds at a steady rate and the nuclear reactor is said to have reached the state of criticality or is said to have become critical. Thus, at the state of criticality, the nuclear fission in the reactor is a controlled fission.

Atomic Power Stations in India:

At present, there are about four atomic power stations working in India. These include:
1) Tarapur atomic power station at Tarapur in Maharashtra.
2) Rajasthan atomic power station in Kota.
3) Madras atomic power station at Kalpakkam in Tamil Nadu.
4) Narora atomic power station in Utterpradesh.

Nuclear Pollution:

The use of nuclear energy produces more pollution than burning of fossil fuels. The various ill effects of using nuclear energy are listed as under:
1) It produces a large amount of harmful radiations, which cause various diseases in humans and other living organisms.
2) It produces a great amount of nuclear wastes, which may prove lethal to both aquatic and terrestrial organisms.
3) The radiations produced in a nuclear plant are invisible and highly penetrating, which penetrate through the bodies of living organisms and cause irreparable damage to cells, which may sometimes end in the death of organisms.

Why is the production of energy by nuclear fission a pollution hazard?

Production of energy by nuclear fission involves many stages such as,
a) Mining and enrichment of the core.
b) Nuclear fission inside the reactor.
c) Disposal of the waste from nuclear reactor.

All these processes involve substances which emit nuclear radiations. Some of these harmful radiations may enter into our environment and pose the danger of radiation pollution. It is due to this reason that the energy production by nuclear fission is considered a pollution hazard.

i) **Radiation pollution caused during the processing of nuclear fuels:** The ‘fuels’ used in nuclear fission reactors are radioactive substances. These substances continuously emit nuclear radiations. These substances are obtained by processing their ores. Mining, processing and enrichment require many chemical/ physical operations. There is always a scope for the leakage of harmful radiations into our environment from any of these processes.

ii) **Radiation pollution caused by leakage of harmful radiation from nuclear reactor:** A nuclear reactor is covered with a thick coat of radiation absorbing material and enclosed in a thick concrete shield. Nuclear reactors are designed for complete safety. However, sometimes-nuclear radiation may escape from the reactor due to
a) Any minor fault in the reactor design.
b) Any natural calamity e.g., earthquake, volcanic eruption etc.
c) Any accidental damage to the reactor.

The leaked radiations pose a permanent threat to the organisms living nearby. These nuclear radiations may cause permanent damage to the body cells.

The two nuclear reactors which were recently involved in the radiation leak are,
a) Nuclear power plant at Three Mile Island (USA), 28 – 03 – 1979. This accident was due to the equipment failure and human error.
b) Nuclear power plant at Chernobyl (in the erstwhile USSR), April 1986. This accident was due to human error.

iii) **Radiation pollution caused by nuclear waste:** The waste matter produced at various stages of the nuclear cycle I.e. from mining to the nuclear reaction inside the nuclear reactor, is called nuclear waste. The nuclear waste is radioactive and continues to emit harmful radiation for a long time.

Sources of nuclear wastes: Nuclear waste is generated,

a) from nuclear reactors
b) during mining of the radioactive materials
c) at nuclear fuel processing complexes.
d) At laboratories and hospitals which use radioactive isotopes for research and medical purposes.

How is nuclear waste disposed off:

The nuclear wastes are highly radioactive. If not disposed off properly, it can cause damage to all living organisms. The question of how to dispose off nuclear waste has been one of the most controversial issues. Presently, the nuclear waste is disposed off by sealing it in corrosion-proof containers which are then stored underground in specially designed deep concrete vaults. Precautions are taken so that it does not come in contact with the upper soil and underground water.

Energy Crisis: The sun is the ultimate source of our energy, but presently man is totally dependent on the major energy sources of coal, petroleum and natural gas. All these sources are non-renewable sources of energy and they can be exhausted at any stage of our development. However, we are quite aware of the fact that a man cannot fulfil all his requirements in the shortage or absence of these energy sources. Scientists have estimated from the current rate of consumption of these energy resources that all the present reservoirs of coal, petroleum and natural gas will last for only upto 200 years from now. This fear that all the present resources of coal, petroleum and natural gas will exhaust soon has created a sort of energy crisis in the whole world. It has compelled us to develop a vis-à-vis strategy to control the present rate of consumption of these energy resources and to use them under a planned and judicious manner. But in the meantime a need has been felt to develop alternative sources of energy to avoid the extra burden over these limited sources. In this regard scientists have achieved the goal upto some extent by developing, solar energy, waste biomass energy, sea wave energy, tidal energy and wind energy etc.

Factors causing energy crises:

The following factors lead to energy crisis:

1. Increasing population.
2. Excessive use of non-renewable (conventional) sources of energy.
3. Use of less fuel-efficient machines.
4. Affluent life style of the people.

What advantages a nuclear energy system has over fossil fuel energy system?

Generation of electricity using a nuclear energy system has the following advantages over a fossil fuel energy system.

a) On equal mass basis, nuclear energy systems produce more energy than fossil fuels such as kerosene, petrol, coal etc. For example, one gram of uranium – 235 produces 8.25×10^7 kJ of energy whereas one gram of coal produces only 30 kJ.
b) If maintained and operated properly, nuclear energy systems produce almost no air pollution. The fossil energy systems viz., thermal power stations, cause pollution of the air and also contributes to the greenhouse effect.
c) Nuclear energy systems consume very little fuel. Once loaded, a nuclear reactor operates for years together. Fossil fuel systems need a few hundred tons of coal everyday.

TEXTUAL QUESTIONS

Ans. 2.

Here heat energy absorbed by unit area of land = 1000 watts.
Also Time duration. = 30 min. = 30 x 60 seconds.
= 1800 seconds.

Thus Total heat energy absorbed = 1000 watts x 1800 seconds.

$$= 1000 \times \frac{1 \text{ Joule}}{1 \text{ second}} \times 1800 \text{ seconds.}$$

= 1800000 Joules = 1.8×10^5 Joules.

Now we also know that; Heat Lost = Heat Gained.

Thus the total amount of heat gained or absorbed by the bucket of water can be calculated as under;

Mass of water = m = 30 Lts = 30 Kg.

And Heat absorbed = Q = 1800000 Joules.

Also Specific heat of water = S = 4200 Joules/Kg/C^0

Therefore using relation:

$$Q = m \times s \times t.$$

Or $1800000 \text{ joules} = 30 \text{ Kg.} \times 4200 \text{ Joules/Kg/}C^0 \times t.$

Or $t = \dfrac{1800000}{30 \times 4200}.$

Or $= \dfrac{1800}{26}.$

$= 14..3\ {}^0C.$

Thus rise in the temperature of the bucket is 14..3 ^{0}C.

Ans. 4. It is clear that energy released from nuclear fusion creates fewer pollution problems that energy from nuclear fission because;

1. The products obtained in the process of nuclear fusion are less radioactive and less harmful than those obtained the process of nuclear fission.
2. The nuclear rays and the radioactive wastes obtained in the process of nuclear fusion are detrimental and less destructive than those obtained in nuclear fission.

Ans. 5. The two main disadvantages of energy systems using nuclear fusion over those using fossil fuels are;

1. The products obtained are more harmful and destructive than those obtained in case of fossil fuels.
2. The nuclear wastes obtained are highly poisonous and destructive than those obtained from fossil fuels.

The two main advantages are;

1. It produces more energy than produced in the energy systems using fossil fuels.
2. It produces energy in a continuous manner and does not requires frequent recharging or refilling as compared to those systems using fossil fuels, which requires frequent recharging or refilling.

Home assignment:

Tick mark the correct answer: -

Q1 The radiation beyond red radiation in the visible spectrum is called

a) Ultraviolet rays b) Microwaves c) Cosmic rays d) Infrared rays

Q2. The major component of the sun is: -

a) Helium b) Hydrogen c) Carbon vapours d) Oxygen

Q3. The process in which lighter nuclei combine to give heavier nucleus and a huge amount of energy is released is called

a) Nuclear fission b) Combustion c) Polymerisation d) Nuclear fission

Q4. The light of the shortest wavelength in the visible spectrum is

a) Red b) Violet c) Yellow d) Ultraviolet

Q5. Nuclear properties of all the isotopes of an element are

a) Same b) Different c) Keep on changing with time.

Q6. An alpha particle is: -

a) Helium atom b) a negatively charged particle c) A neutral particle d) A doubly ionised helium atom.

Q7. An isotope of hydrogen having one neutron and one proton in its nucleus is named

a) Protium b) Tritium c) Deuterium d) Hydrogen

Q8. The most common fuel for a fission reactor is

a) Uranium – 235 b) Uranium – 238 c) Californium – 238 d) Thorium – 234

Q9. The element other than uranium which is easily fissionable is:

a) Californium – 248 b) Thorium – 234 c) Uranium – 238 d) Plutonium – 239

Q10. The nuclear fission reactions controlled by

a) Coolant b) Moderator c) Control rods d) Core size

Q11. Nuclear fusion occurs in:

a) Atomic bomb b) Hydrogen bomb c) Neutron bomb d) Nuclear reactor

Q12. When a nucleus emits an alpha particle, its atomic mass

a) Decreases by 2 units b) Increase by 2 units

c) Decreases by 4 units d) Increase by 4 units

Q13. The controlled nuclear fission reaction is carried out in a:

a) Thermopile b) Nuclear reactor c) Thermostat d) Cloud chamber

Q14. Which of the following is the safest from the point of view of health hazard?

a) Petroleum b) Nuclear energy c) Solar energy d) Coal

Q15. The non-polluting renewable source of energy is:

a) Sunlight b) Coal c) Petroleum d) Nuclear energy

Q16. Which of the following rays is most harmful to a human body?

a) Alpha particles b) Cathode c) Gamma rays d) A ray of beta particles