General Science

Short Answers

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Nuclear Technology

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CHAPTER 7: NUCLEAR TECHNOLOGY

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7.1 INTRODUCTION TO NUCLEAR TECHNOLOGY

Homi Jahangir Bhabha fostered the development of the Indian nuclear program and as a result of his vision and the work of several scientists in the field, India is the only developing country that is self-reliant in nuclear technology. This is despite the presence of many international technology control regimes in the nuclear arena.

The genesis of nuclear science in India can be traced back to the establishment of the Tata Institute of Fundamental Research (TIFR), in Bombay in 1945, by Homi Jahangir Bhabha. Since then India has been making rapid strides both domestically and at the global stage in nuclear science research and technology. Today it has harnessed the arena of nuclear technology for the generation of electricity and also nuclear techniques have been used in the field of medicine, agriculture, industry among others.

7.2 DEPARTMENT OF ATOMIC ENERGY (DAE)

The Department of Atomic Energy, responsible for the development of nuclear power technology in India, was formed on 3rd August 1954.

Apart from developing nuclear technology, the DAE is also in charge of developing radiation technology for applications in the fields of medicine, industry, agriculture and basic sciences.

Department of Atomic Energy (DAE) was established with the following objectives:

- Generating electricity from nuclear energy through the use of the naturally available uranium and thorium in India
- Building research reactors and implementing the radioisotopes produced in reactors for application in the fields of agriculture, industry and medicine
- Developing advanced technology in domains like lasers, accelerators, information technology and biotechnology
- Developing materials including strategic and non-nuclear ones like titanium
- Playing a role in national security
- Contributing to industrial development by promoting technology transfers and interaction with the industry
- Offering support to fundamental research in nuclear energy and other areas in science
- Coordinating with academic institutions to enhance the quality of education and research and also offering research grants to these institutions
- Promoting international collaboration in fields of advanced research and big science projects.

The apex body of the DAE is the Atomic Energy Commission (AEC)

The DAE is headquartered in Mumbai. The department executive is the Chairman of the AEC, who is the ex-officio executive head of the department. This department is directly under the Prime Minister of the country.

This department has 6 research institutions, 5 public sector companies, 3 industrial organizations, 3 service organizations and 3 universities under it. The DAE also supports many other research institutes of eminence in India.

7.3 NUCLEAR ENERGY

Nuclear Energy is the energy at the core of an atom. Normally, the mass of an atom is concentrated at the center of the nucleus. Neutrons and Protons are the two subatomic particles that comprehend the nucleus. There exists a massive amount of energy in bonds that bind atoms together.

Nuclear Energy is discharged by nuclear reactions either by fission or fusion. In nuclear fusion, atoms combine to form a larger atom. In nuclear fission, the division of atoms takes place to form smaller atoms by releasing energy. Nuclear power plants produce energy using nuclear fission. Sun produces energy using the mechanism of nuclear fusion.

Nuclear Reactions

- Nuclear reactions convert one element into a completely different element.
- Suppose if a nucleus interacts with any other particles then separates without altering the characteristics of other nuclei then the process is called **nuclear scattering** rather than specifying it as a nuclear reaction.
- This does not imply radioactive decay.
- One of the most evident nuclear reactions is the nuclear fusion reaction that occurs in fissionable materials producing induced nuclear fission.

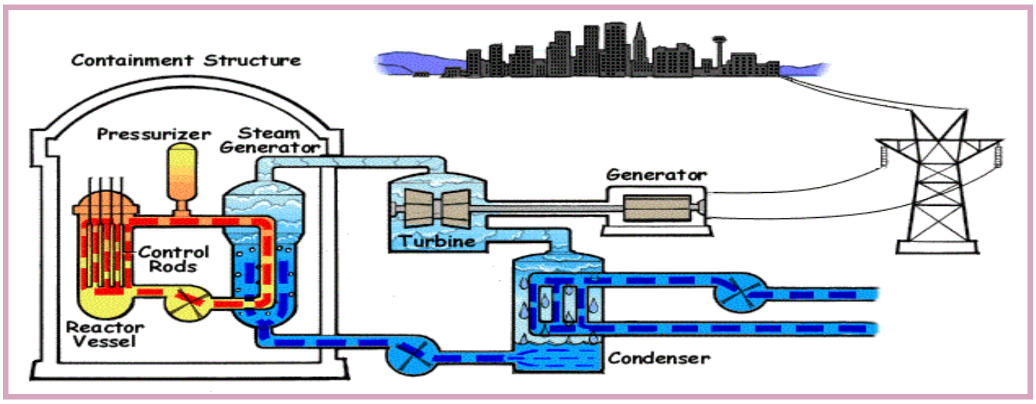


Fig 7.1: Nuclear Energy Cycle

Source: BYJUS

Applications of Nuclear Energy

- Nuclear medicine
- Nuclear Technology is used in Industries
- Agricultural uses of nuclear technology
- Environmental uses of nuclear technology
- Biological Experimentations
- Medical diagnosis and treatments
- Scientific Investigations
- Engineering Projects
- Neutron Activation Analysis

7.4 NUCLEAR POWER IN INDIA

Currently, India is having 22 Nuclear Reactors that are operational in the 7 nuclear plants, having a total installed capacity of 6,780 MW. Nuclear power supplied around 4% of electricity in India in year 2018. Seven more nuclear reactors are under construction with a cumulative generation capacity of 4,300 MW.

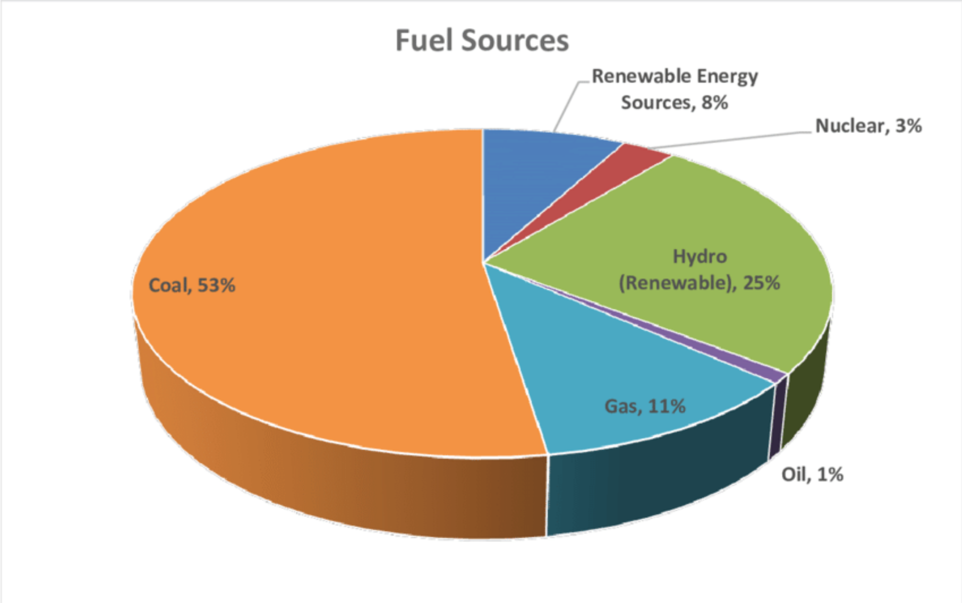


Fig 7.2: Share Of Nuclear power in India

(Image source: India energy portal)

NUCLEAR POWER PLANTS

- Tarapur Atomic Power Station (TAPS), Maharashtrais operated by Nuclear Power Corporation of India Limited (NPCIL) has a capacity of 1400 MW
- Rawatbhata Atomic Power Station (RAPS), Rajasthan is operated by NPCIL. It uses a Pressurized Heavy Water Reactor (PHWR) and has a total capacity of 1180MW.
- Madras Atomic Power Station at 440 MW capacity.
- Kudankulam nuclear power plant, Tamil Nadu is operated by NPCIL. The plant has a capacity of 2000MW and uses Water-Water Energetic Reactor (WWER) that is based on a series of designs of pressurized water reactor
- Kaiga generating station, Karnataka is operated by NPCIL. Its total capacity is 880 megawatts.
- Narora Atomic Power Station in (NAPS), Uttar Pradesh is operated by NPCIL. Its total capacity is 440MW
- Kakrapar Atomic Power Station (KAPS), Gujarat with 880MW capacity

Fig 7.3: Atomic Power Stations

(Image source: Philophysics forum)

One of the main reasons for the low capacity factors of nuclear power in India is lack of nuclear fuel. India has been making advances in the field of **Thorium based fuels** and trying to design and develop a prototype for an atomic reactor using thorium and uranium (low enriched), which forms a key part of the 3 stage Nuclear programme of India. The country has also recently re-initiated its involvement in the low energy nuclear reaction research activities, in addition to supporting work done in the fusion power area through the International Thermonuclear Experimental Reactor initiative.

The Government of India has made nuclear energy its priority, and intends to augment the share of Nuclear Energy in total energy generation from around 3.5% to 25 % by the year 2050. Recently, India has been trying to ramp up its capacity for nuclear generation and for this it has also been supported by its strategic partners such as USA, AUSTRALIA, JAPAN among Other nations.

7.5 NUCLEAR POWER PROGRAMME

India’s 3 stage Nuclear Power Program was conceived soon after Independence to meet the security and energy demands of Independent India. India’s Uranium reserves constituted a very small amount, but India has a very huge amount of thorium reserves. Hence to attain independence in the energy domain it was conceived to develop a 3 stage nuclear power program utilising the abundant thorium reserves.

India’s 3 stage Nuclear Power Program was devised in 1954.

Locations of Nuclear Power Plants – Planned in India

- Gorakhpur
- Chutka – Madhya Pradesh
- Mahi Banswara – Rajasthan

Locations of Nuclear Power Plants – Proposed

- Rajouli, Nawada – Bihar
- Bhimpur – Madhya Pradesh
- Jaitapur (Ratnagiri District) – Maharashtra
- Kovvada (Srikakulam District) – Andhra Pradesh
- Nizampatnam (Guntur District) – Andhra Pradesh
- Pulivendula (Kadapa District) – Andhra Pradesh
- Chhaya – Mithi (Bhavnagar District) – Gujarat

Locations of Uranium Resources

- Tummalapalle (Kadapa District) – Andhra Pradesh
- Nalgonda District – Telangana
- East Singhbhum District – Jharkhand
- West Khasi Hills District – Meghalaya
- Udaipur District – Rajasthan
- Yadgir District – Karnataka
- Rajnandgaon (District) – Chhattisgarh
- Sonbhadra District – Uttar Pradesh
- Rudraprayag District – Uttarakhand
- Una District – Himachal Pradesh
- Gondia District – Maharashtra

Rationale for the three stage Nuclear Programme:

- India has only 2% of World's Uranium reserves, on the other hand, India has 25% of the World's Thorium reserves.
- Since India was not part of some of the International Nuclear treaties, India was prevented from taking part in international trade in the nuclear field.
- India has a huge population and growing economy, to meet the energy demands India had to rely heavily on imports of coal, and crude oil.

- Hence India had to devise methodologies to be self-sufficient in meeting energy demands arising due to a burgeoning population and economy; the 3 stage Nuclear Power Program was one of the answers to it.

Thorium is not a fissile material, but it can be converted into Uranium – 233, which can then undergo fission to produce energy.

7.6 STAGE-I OF NUCLEAR POWER PROGRAM

For the 1st stage the Reactors that were chosen was a Pressurised heavy water reactor (PHWR). However to gain operational experience initially and atomic power station comprising two Boiling water actors (BWR) was set up at Tarapur (Maharashtra).

Later on the first two Pressurised heavy water reactors (PHWR) at Rawatbhata started commercial operations in 1973 and 1981. While the first unit of the reactor was built with the help of Atomic energy of Canada limited, the second unit was completed with the indigenous research and development efforts and with the support of Indian industry. Due to this success, a number of reactors were commissioned in India.

A pressurized heavy water reactor is a reactor that commonly uses unenriched natural uranium as its fuel, while it uses heavy water as its coolant and moderator. The heavy water coolant is kept under pressure allowing it to be heated to high temperatures without boiling much as in a Pressurised water reactor.

7.7 NUCLEAR FUEL CYCLE

Nuclear Fuel Cycle is an array of an industrial process which includes a production of electricity from uranium in nuclear reactors. It can be defined as various activities that are related to generating electricity from nuclear reactions. Nuclear fuel cycle also termed as nuclear chain reaction comprises a front end, service period and back end. The front end consists of steps that are necessary for preparation of fuel, service period involves steps in which fuel is utilized during the time span of a nuclear reactor, and back end comprises steps that are essential for managing, conversion or disposal of used fuels. If used fuel is not converted for reuse then the process is defined as an open fuel cycle. If used fuel is converted for reuse then the process is described as a closed fuel cycle. Let’s consider uranium. It is placed in a reactor for an average of three years to generate electricity. Once the electricity is produced, used fuel further undergoes various steps that are mentioned above.

7.8 URANIUM

Uranium is found in rocks, rivers, sea water and in most of the solids. It is one most slightly radioactive metal. In most of the places in the world, the concentration of this metal is adequately high in the ground. They are extracted and used as a nuclear fuel.

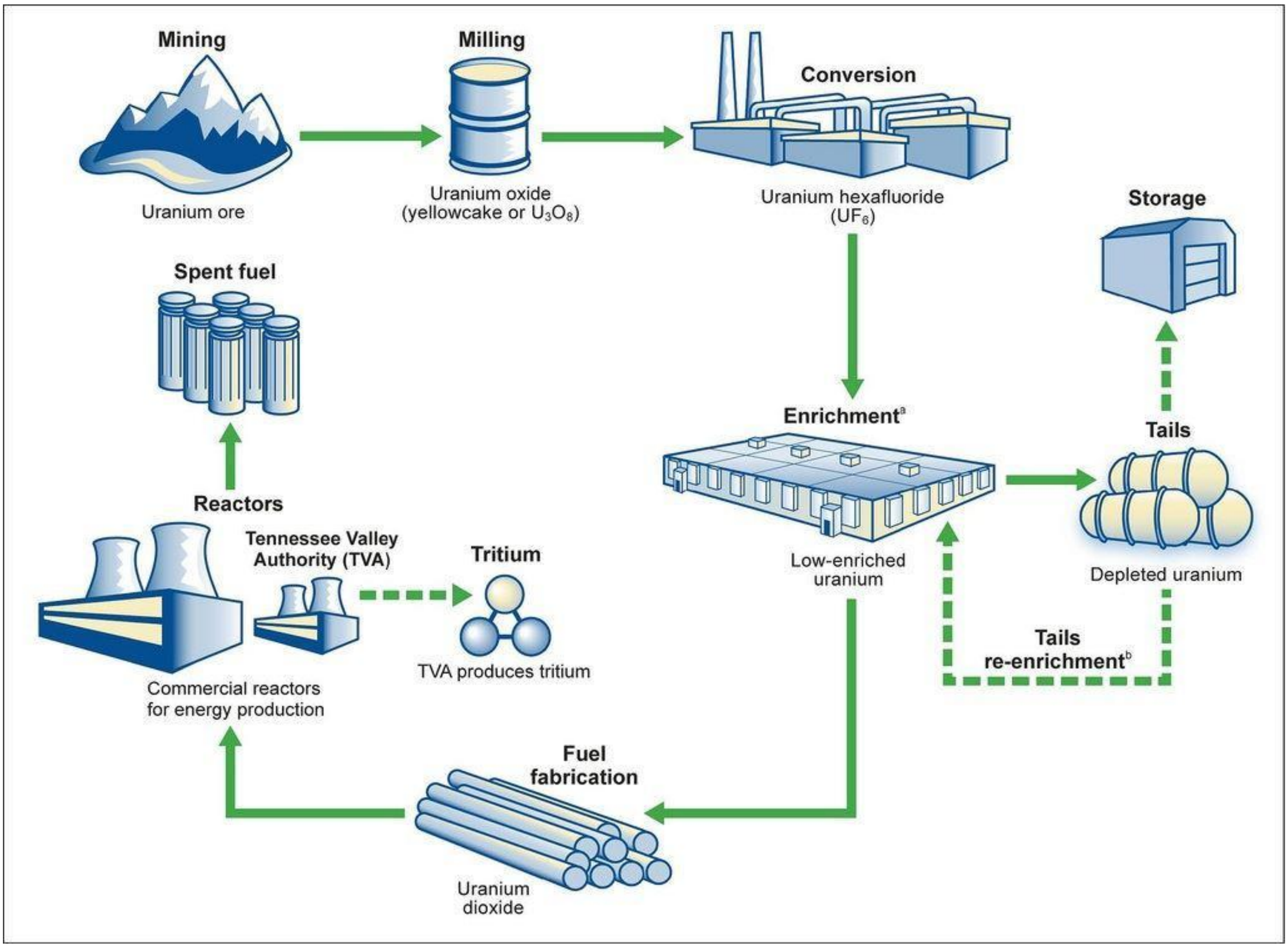


Fig 7.4 :Fuel Cycle

(Image source: Byjus)

Uranium Mining	Uranium Milling	Conversion of Uranium
Two methods are used to recover uranium ore, evacuation, and situ techniques. Evacuation may be open pit mining. The Situ process involves oxygenated groundwater that is circulated through the pores of an orebody to soften uranium	It is carried out near to the site of a uranium mine. A majority of mining facilities involve a mill; wherein a single mill can process ores from several mines. Milling involves a production of uranium oxide concentration that is carried out from the	It includes the conversion of uranium oxide into uranium hexafluoride. This product only consists of natural uranium, not the enriched product. Uranium hexafluoride is converted in gaseous form at a moderate temperature of 57 °

oxide and to bring it to the surface. The convention mill is used to restore uranium oxide from a solution.	mill.	
Enrichment	**Fabrication**	**Power Generation**
The concentration of U-235 is less than a requirement to sustain a nuclear chain reaction. Hence it has to be enriched in fissionable isotopes and it is carried through two processes namely low-enriched uranium and simply depleted uranium.	In this process, uranium dioxide is converted into pellet form. The pellets are fired at a very high temperature to form enriched uranium and then undergo a grinding process. These pellets are connected through metal tubes organized in a fuel assembly to assure consistency in the fuel.	The core of a reactor is made up of several hundreds of fuel assemblies. U – 235 isotopes split producing an excess of heat. This process is known as a chain reaction and it entirely depends upon the type of moderator namely graphite or water

Note:- In some countries depending upon the policies, used fuels may be shipped into central storage facilities.

FUEL REPROCESSING

The indian nuclear power program is based on a closed **fuel cycle** under which the spent or used fuel namely **Plutonium** or **U-233** is recycled. Right since the inception of the programme the Department of Atomic Energy has been developing the technology of fuel REPROCESSING.

There are pilot plants for fuel reprocessing at Trombay, that reprocess fuel from research reactors and industrial scale plants at Tarapur and Kalpakkam that reprocess fuel from power reactors.

7.9 STAGE -II OF NUCLEAR PROGRAM(FAST BREEDER REACTORS)

- This stage of nuclear power program consists of Fast Breeder Reactors (FBRs). These reactors use Plutonium-239 which is recovered as a byproduct from First Stage and natural Uranium for fuelling the reactor.

- In FBR, the Plutonium 239 undergoes fission and produces energy. The Uranium-238 present in the fuel gets converted into additional Plutonium-239 by absorbing a fast moving neutron.
- The FBR use produces more fuels than what is spent, that is: for every 1 kg of plutonium spent, around 1.1 kg of Pu-239 is produced as a byproduct.
- After building sufficient reserves of Plutonium-239, thorium can be used as a blanket material inside the reactor which gets transmuted to U-233 to be used in the third stage.
- The surplus Plutonium-239 that is produced in each Fast breeder reactor can be utilised for setting up more FBRs.

The first prototype FBR has been built at the Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, Tamil Nadu which achieved criticality in 2019. It has been utilising Uranium -Plutonium carbide fuel.

Based on the above experience the Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI) is building a 500 MW pool type reactor using a mixed Uranium - Plutonium Oxide fuel

For achieving 2500 MW of electricity capacity from five FBRs, Construction of four more FBRs has been planned

7.10 STAGE - III NUCLEAR POWER PROGRAM (THORIUM BASED REACTORS)

Thorium utilisation is the core objective of the Nuclear power program of India.The Thorium based reactors will be thermal breeder reactors which can be refueled with naturally occurring thorium after the initial fuel charge.

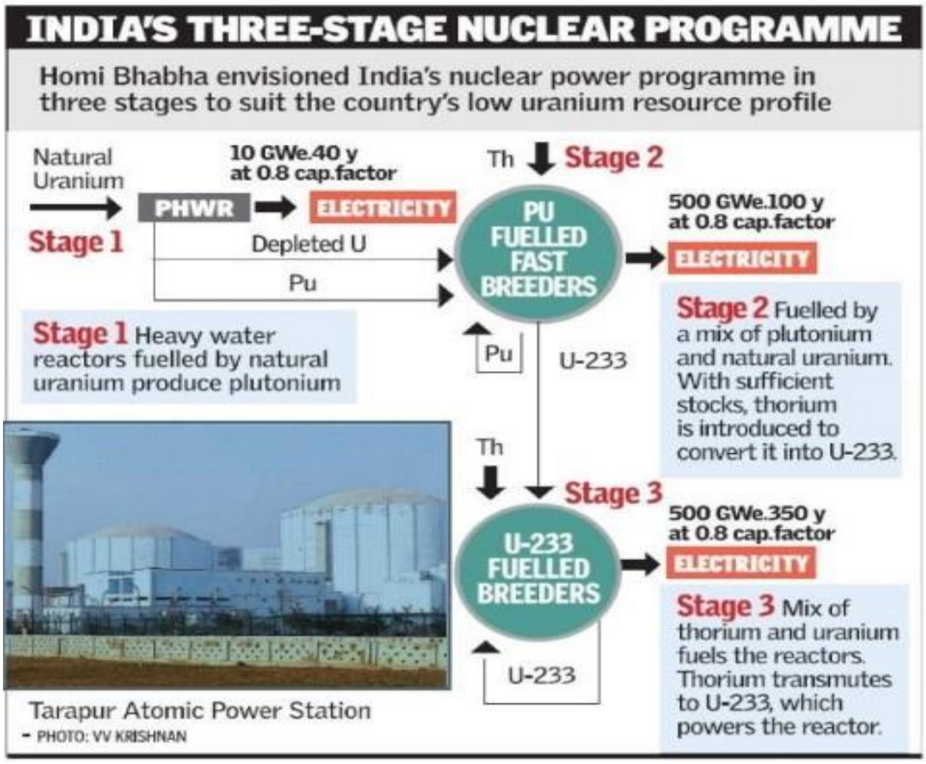
Large scale deployment of thorium based reactors can only be expected after 3-4 decades of commercial operation of fast breeder reactors. Due to the large delay for direct thorium based nuclear power programme, India is looking for reactor designs which could allow direct use of thorium in parallel with a sequential three stage programme. However beginning has already been made by introducing forum uranium cycle in Pressurised heavy water reactors and research reactors.

India is considering three options in the development of thorium based reactors that include

- Accelerator Driven Systems (ADS),
- Advanced Heavy Water Reactor, (AHWR)
- Compact High Temperature Reactor.

Advanced Heavy Water Reactors are to be fuelled with 20% Low Enriched Uranium (LEU) and 80% Thorium. Low enriched uranium is available in the world market which can be utilised in these reactors. Moreover the research reactor at KALPAKKAM MINI REACTOR (KAMINI) utilises uranium fuel which is derived from Thorium, in radiography of various materials.

For the separation of Uranium-233 from irradiated thorium fuel on a plant scale,a Uranium-Thorium separation facility is in operation at Trombay.



<u>**Fig 7.5: Three Stage Nuclear programme**</u>

(Image source: The Hindu)

<u>**Limitations/Challenges in development of Thorium based reactors**</u>

Thorium cannot sustain the chain reactions by itself and constantly requires fissile material like uranium or plutonium for transmuting Th-232 to U-233.Shortage of Uranium fuel which is required for converting the fertile fuel thorium into fissile fuel capable of sustaining a chain reaction is the biggest obstacle for the development of thorium fuelled reactors in India.

INDIA AT CERN

Indiahas had some of the biggest contributions to CERN,and is involved in various programmes like computing, power supply systems, hi-tech components, and high precision mechanics.Of the total 18000 scientists working with CERN from from all over the world, around 400 are from India and India has major contributions in all the experiments: ranging from the the Large Hadron Collider, the ATLAS ,compact muon solenoid and the ALICE experiments.india had associations with CERN since the 1970s, while eit became an associate member in 2017.

Also India has increasingly contributed to the different mega science projects like International Thermonuclear Experiment Reactor (ITER), Large Hadron Collider (LHC) at CERN, the Square Kilometer Array (SKA) and the India based Neutrino observatory and the LIGO.

Large Hadron Collider (LHC):

During the making phase of Large Hadron Collider (LHC): Indian scientists have been involved in the design of many components of the LHC, whereas construction of those took place by scientists and engineers through Indian industries. Some of them include superconducting corrector magnets, precision magnetic positioning system jacks, accelerator protection systems, quench detection electronics, vacuum system design for long beam transport lines and cryogenic systems.

ALICE EXPERIMENT:

ALICE experiment: Indian scientists have played a significant role in the ALICE experiment, which is a dedicated experiment for search and study of Quark Gluon Plasma (QGP). Hardware contributions to the ALICE detector include the Photon Multiplicity Detector (PMD), the Muon Spectrometer, the MANAS chip, and Silicon pad detectors. The PMD is a fully Indian effort from conception to commissioning. The QGP research program of ALICE is on the quest to get a glimpse of how matter behaves within a few microseconds after the birth of our Universe. Indian scientists have contributed to the physics analysis, which led to the discovery of the QGP matter and its characterization.

CMS - India:

CMS experiment: Indian scientists have played a major role in the CMS experiment, which is one of the two experiments that discovered the Higgs Boson. Our scientists have been involved in the design and manufacture of the Hadron Barrel Outer Calorimeter; Silicon strip based pre-shower detector and RPC detectors, which were installed recently. Indian scientists have contributed to the physics analysis that led to the discovery of Higgs Boson and a detailed study of Quark-Gluon Plasma, a form of matter in the early Universe.

WLCG: INDIA;

GRID computing: Experiments at CERN produce colossal amounts of data (roughly 30 petabytes a year), which are processed using Grid computing, enabling sharing of resources belonging to computer centers located around the world. Indian scientists have contributed substantially to the building and operation of the Large Hadron Collider Grid (LCG). LCG has a hierarchical structure of data dissemination, of which India hosts two Tier 2 centres at Variable Energy Cyclotron Centre (VECC) and Tata Institute of Fundamental Research (TIFR), in addition to several Tier 3 centers. The two Tier-2 Grid computing centres at VECC and TIFR are performing a large part of LHC computing.

7.11 NUCLEAR FUSION

Nuclear fusion is the process where the nuclei of two light atoms combine to form a new nucleus. This is another way of producing nuclear energy, like nuclear fission, although in nuclear fission the nucleus of a heavier atom splits. Now let us learn how the energy is produced by nuclear fusion.

When two light nuclei combine in a fusion reaction, the combination has a mass that is less than the mass of the initial individual nuclei. This means that the reaction gives out energy according to Einstein's mass-energy equivalence.

An example of a fusion reaction is that of the combination of Deuterium and Tritium, which are isotopes of Hydrogen to give Helium and release a neutron and give out around 17 MeV of energy.

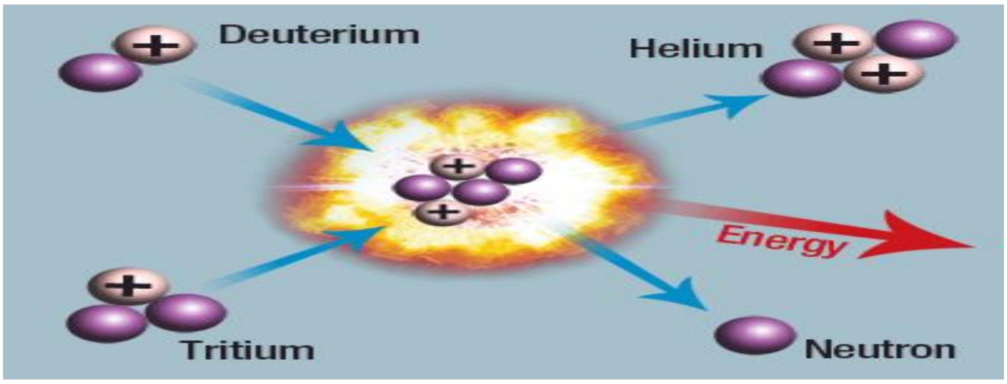


Fig 7.6 Nuclear Fusion

(Image source:byjus)

Nuclear binding energy: It is defined as the energy required to split the nucleus of an atom into its components.

Nucleon: It is defined as one of the subatomic particles i.e. proton or a neutron.

Fusion: It is defined as a nuclear reaction in which the nuclei combines to form a massive nuclei with release of neutrons and energy.

7.12 NUCLEAR FUSION REACTORS

There are several research projects and experimental reactors which are under test and being funded by Private and Public sectors. Some of these new fusion projects are utilising the newest generation of supercomputers for better understanding and tweaking the behavior of the ultrahigh-temperature plasma in which hydrogen nuclei fuse to form helium. Others have reopened promising lines of inquiry that were shelved decades ago. Still others are exploiting new superconductors or hybridizing the mainstream concepts.

Few of these new experimental projects are as under:

Magnetic Confinement

Here, the hot plasma is checked from touching the walls of the confining material by use of magnetic fields. The temperatures achieved are extremely high and therefore they are kept from touching material.

However this technology is still at a nascent stage and scientists are a long way from achieving a self-sustaining reaction, and from preventing neutron activation from destroying the reactor's walls.

Inertial Confinement

Here, the high energy density is put into a small pellet of reactors fusing them in such a short span that they don't have the time to touch the confining material. Powerful pulsed laser or ion beams compress a small fuel pellet to extremely high densities, and the resulting shock wave heats the plasma before it has time to dissipate.

But there are issues with this type of fusion because the forces exerted on the fuel pellet result in laser-plasma instabilities that produce high-energy electrons, which heat and scatter much of the fuel before it can fuse. Moreover due to the high cost of laser and several complexities associated with it makes the traditional approaches to Inertial Confinement unsuitable for energy production.

Magnetic Inertial Fusion

Also known as Magnetized Target Fusion,this is a hybrid approach which uses magnetic fields to confine a lower-density plasma (as in magnetic-confinement fusion),that can be heated and compressed using an inertial-confinement method such as lasers or pistons (as in inertial-confinement fusion). But in order for this technique to work the scientists are yet to find a way to increase the plasma density at a working level and keep it there so long enough that a significant fraction of the fuel mass gets fused.

Stellarator

The stellarator's spiraling ribbon shape produces high-density plasma that's symmetrical and more stable than a Magnetic Confinement Reactor, allowing the reactor to run for long periods of time. But the challenge with this kind of reactor is its design which is hard to be built and extremely sensitive to imperfect conditions.

However, some of the groups involved in building these reactors are predicting significant fusion milestones within the next five years, including reaching the breakeven point at which the energy produced surpasses the energy used to spark the reaction. As the threat of climate change looms large over the world it is imperative that one of these projects gets commercialized and succeed in order to mitigate harmful effects of climate change and simultaneously fulfill the energy requirements of a large scale population.

7.13 ADVANTAGES AND DISADVANTAGES OF NUCLEAR FUSION

Advantage

It is a safe source for the generation of electricity.	It is economic and sustainable.	The amount of fuel available in nature is abundant and is inexpensive.	The greenhouse gases produced during the process of fusion is minimal.

Limitations of Nuclear Fusion Technology

There have been several efforts by the government of most of the developed Nations like the USA ,France ,Germany etc but there were project delays and cost overruns which came as a setback to most of the governments.

Although there is abundant fusion energy in nature, in the form of thermonuclear fusion which powers stars and the sun, the task of triggering and controlling a self-sustaining fusion reaction and harnessing its power is arguably the most difficult engineering challenge humans have ever attempted.

Also most of the challenges arise in fusion energy due to issues with heating, containing and controlling the plasma. The neutron radiation in a nuclear fusion reactor damages the reactor's walls which must be replaced frequently and disposed of as low-level radioactive waste.

Nevertheless,several of the new initiatives mentioned above are underway to overcome the challenges and run few concept projects on Nuclear fusion energy in order to materialise the envisaged dream into a reality.

7.14 NUCLEAR FISSION

Nuclear fission is the process of splitting a heavy nucleus, such as uranium or plutonium, in two smaller nuclei of nearly the same mass. During this process, the unstable radioactive nucleus is split into two smaller nuclei. Nuclear fission can occur spontaneously in some cases or can be induced by the bombardment on the nucleus with a variety of particles (e.g., protons, or neutrons or alpha particles) or by gamma rays radiation.

During this fission process, a huge amount of energy is produced further giving rise to radioactive elements as well as the release of many neutrons. These neutrons can further induce chain fission reaction in the nucleus of the uranium or plutonium and release more neutrons. This can result in an uncontrolled chain reaction till all the starting material is exhausted where a large amount of energy is also produced.

If such reactions can be controlled in a nuclear reactor, these chain reactions can be harnessed to meet the electricity needs of society. On the other hand, such uncontrolled reactions can lead to the formation of atom bombs, which can be very devastating.

The modern "Atomic Age" is attributed to the discovery and developments in the field of nuclear fission. This has its own boon and bane. It's judicious usage and development can help us to develop at a great speed and in a sustainable manner but if it falls in the wrong hands it can cause a great threat to humanity. However, there is still a great scope of development and research in this field and still many more questions are to be answered.

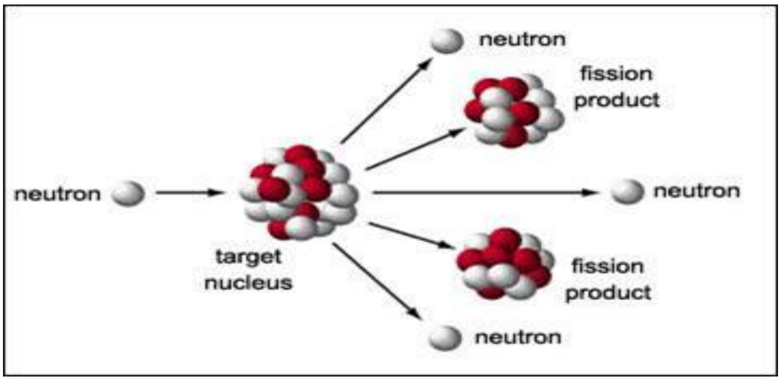
As mentioned above the splitting of neutrons results in the release of a large amount of energy. During this process, there is a strong repulsion force between the protons. But, they are also bound together by the strong nuclear force. Typically, each proton applies a repulsion force of 20N on every other proton and that is equal to the force of a hand resting on a person's lap. This is really a very large force for these atomic particles.

Due to such a large force inside the small nucleus, it leads to the production of a large amount of energy and is enough to cause a considerable reduction in mass. This implies that the total mass of each of the fission fragments is less than the mass of the starting nucleus. Here the missing mass is called the mass defect.

It is easy to understand the amount of energy that binds all the nuclei together. Every nucleus has this binding energy except hydrogen. Therefore, the binding energy available to each nucleon is simply called the binding energy per nucleon. The same amount of energy is actually required per nucleon to split a nucleus.

The products formed after fission are more stable means further splitting is very hard. As this binding energy for fission products is very high, the nucleonic mass becomes lower. The result of this large binding energy and lower mass results in the release of energy. Nuclear binding energy and mass defects are also used interchangeably.

When a nucleus fissions reaction takes place, the neutron breaks the target nucleus into further smaller products. These fission products are nearly equal to half the original mass. Two or three neutrons are also emitted.



<u>Fig 7.7 Nuclear Fission</u>

(Image source:byjus)

7.15 NUCLEAR FISSION REACTION

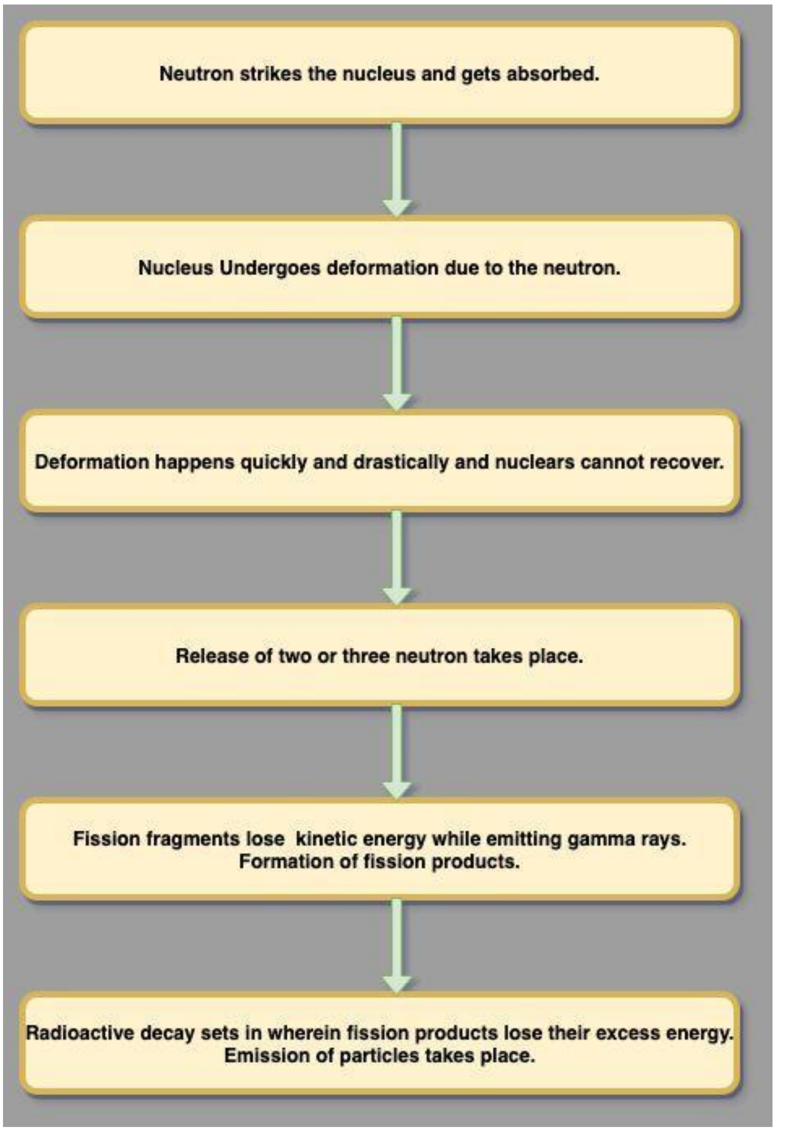


Fig 7.8 Steps in Fission Reaction

(Image source: byjus)

Nuclear Fission Reactor

A nuclear reactor is the most important part of a nuclear power plant. This is the place where nuclear chain reactions occur that produce energy by fission. The heat thus produced can be used to produce electricity.

The main purpose of a reactor is to contain and control energy released. Uranium is used as the nuclear fuel in the reactors. The uranium is treated with ceramic pellets and they are sealed in the form of metal tubes called fuel rods. Generally, about 200 such rods are assembled together to form a fuel assembly. When a hundred of such assemblies are assembled together, it is called the core.

The fuel rods are dipped in water in the reactor, which functions as both a coolant and moderator. The job of the moderator is to slow down the neutrons produced by fission to control the chain reaction. Control rods may be immersed in the reactor core to reduce the reaction rate or pulled out to increase the same. The heat produced by such reactions converts the water into steam, which is further converted into carbon-free electricity by the help of turbines.

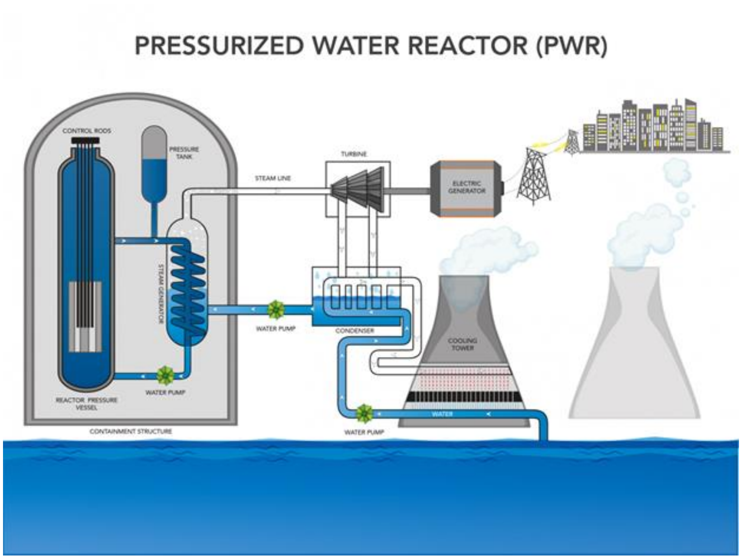


Fig 7.9 Nuclear Fission Reactor

(Image source: byjus)

Advantages

- Clean Alternative Source of Energy:-Nuclear fission is one of the most researched and well-known topics of nuclear technology. This has been utilized as a very clean alternative source of energy. It will not be a hyperbole if we tell it as “the energy source of the future”. This technology is now achieving perfection and excellence and emerging at a very fast pace compared to other alternative sources of energy.

- **Fulfil The Needs Of The Present And Future Generation:**An enormous amount of energy is produced by the process of nuclear fission, which can be utilized to fulfil the needs of next-generation high tech cities, and industries. As this is a very rapid reaction, energy can be produced depending on the requirement with greater reliability.
- **Reduced Threat From Greenhouse Gases Production And Global Warming:**In contrast to fossil fuels, which causes serious damage to the environment, nuclear fission produces energy without releasing greenhouse gases into the atmosphere, which reduces the effects of global warming and even helps fight pollution.
- **Extremely Low Operation Cost:**The cost of operation is very low once the nuclear power plant is commissioned. The costs in operation are only the payment of workers to run the plant and the cost of the raw materials required.

Disadvantages

- **Higher Risk of Radiation Exposure:**The radiation emitted during the fission reaction is extremely harmful to humans and animals. The workers who are exposed while working at nuclear power plants are at great risk radiation poisoning, cancer and other diseases associated with radiation.
- **Highly Vulnerability:**High vulnerability is a potential risk that is involved in nuclear power plants. The enormous energy produced in a fission reaction can be utilized to create nuclear weapons. Any small accident at a nuclear plant can cause huge damage, affecting the lives of millions.
- **Radioactive Contamination Risk:**The waste that is released from the nuclear power plant is highly radioactive and harmful for all living beings. There are high chances of water contamination from these plants which can cause serious diseases and death in living beings.
- **High Cost Of Plant Commissioning:**To build a nuclear power plant requires a huge investment, and this is due to the latest technologies and safety measures that are required to run it properly.

7.16 RADIOACTIVITY

Due to nuclear instability, an atom's nucleus exhibits the phenomenon of Radioactivity. Energy is lost due to radiation that is emitted out of the unstable nucleus of an atom. Two forces, namely the force of repulsion that is electrostatic and the powerful forces of attraction of the nucleus keep the nucleus together. These two forces are considered extremely strong in the natural environment. The chance of encountering instability increases as the size of the nucleus increases because the mass of the nucleus becomes a lot when concentrated. That's the reason why atoms of Plutonium, Uranium are extremely unstable and undergo the phenomenon of radioactivity.

Some Important Terms Related To Reactor

CHAIN REACTION:it refers to a process where neutrons released in fission produce an additional fission in at least one further nucleus. Then the nucleus in turn produces neutrons, and this process goes on repeating itself. The process may be controlled (nuclear power) or uncontrolled (nuclear weapons).

CONTROLLING RODS: DescriptionControl rods are used in nuclear reactors to control the fission rate of uranium or plutonium.these rods are generally composed of chemical elements such as boron, cadmium, silver, or indium, that are capable of absorbing many neutrons without themselves fissioning

MODERATOR: These are used in a Nuclear Reactor to regulate the speed of fast moving neutrons. Generally light water is used as a neutron moderator. Other alternatives include beryllium, graphite ,heavy water .

TYPES OF NUCLEAR REACTORS

BOILING WATER REACTOR

These are a type of light water nuclear reactor usually used for the generation of electrical power. After the PRESSURISED WATER REACTORS(a type of nuclear water reactor) ,It is the second most common type of electricity-generating nuclear reactor. A boiling water reactor (BWR) uses demineralized water as a coolant and neutron moderator. Heat is produced by nuclear fission in the reactor core.

PRESSURIZED WATER REACTORS

The core inside the reactor vessel creates heat.

Pressurized water in the primary coolant loop carries the heat to the steam generator.

Inside the steam generator, heat from the primary coolant loop vaporizes the water in a secondary loop, producing steam.

The steamline directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity.

The unused steam is exhausted to the condenser, where it is condensed into water. The resulting water is pumped out of the condenser with a series of pumps, reheated, and pumped back to the steam generator. The reactor's core contains fuel assemblies that are cooled by water circulated using electrically powered pumps. These pumps and other operating systems in the plant receive their power from the electrical grid. If offsite power is lost, emergency cooling water is supplied by other pumps, which can be powered by onsite diesel generators. Other safety systems, such as the containment cooling system, also need electric power. PWRs contain between 150-200 fuel assemblies.

PRESSURISED HEAVY WATER REACTORS

It is a nuclear power reactor,which generally uses unenriched natural uranium as its fuel, that uses heavy water (deuterium oxide D2O) as its coolant and moderator. The coolant ,that is;the heavy water, is kept under pressure, allowing it to be heated to higher temperatures without boiling, much as in a typical pressurized water reactor.although heavy water is quite expensive than ordinary light water, it yields greatly enhanced neutron economy, allowing the reactor to operate without fuel enrichment facilities (mitigating the additional capital cost of the heavy water) and generally increasing the ability of the reactor to efficiently make use of alternate fuel cycles.

ADVANCED HEAVY WATER REACTORS

It is a kind of latest invention and design for the next generation. The advanced heavy-water reactor (AHWR) burns thorium in its fuel core. The AHWR will form the third stage in India's three-stage fuel-cycle plan. It is a thorium fuel based vertical pressure tube type, heavy water moderated and boiling light water cooled reactor. This AHWR having 300 MWe capacity is designed by BARC and is intended to serve as a technology demonstrator for a range of technologies for Thorium utilisation as well as for a number of enhanced safety features that have been incorporated.

RESEARCH AND DEVELOPMENT IN INDIA

The Department of Atomic Energy is involved in the research and development activities related to nuclear technology through its five organisations. Moreover, it also gives financial assistance to allied Institutes and also promotes research activities in academies and universities.

7.17 BHABHA ATOMIC RESEARCH CENTRE (BARC)

The Bhabha Atomic Research Centre (BARC) is the premier nuclear research facility of India, it is headquartered in Trombay (Mumbai) Maharashtra. The centre comprises a number of multi-disciplinary research facilities with extensive infrastructure for advanced research and development that covers the entire range of areas related to nuclear science, engineering and related areas.

The core mandate of BARC is to sustain peaceful applications of nuclear energy, primarily for power generation. It manages all facts of nuclear power generation, from theoretical design of reactors to, computerised modelling and simulation, risk analysis, development and testing of new reactor fuel materials, etc. BARC is also involved in research areas related to spent fuel processing and safe disposal of nuclear waste. Also, other research focus areas are applications for isotopes in industries, medicine, agriculture, etc.

7.18 INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH, KALPAKKAM (IGCAR)

This centre for atomic research is the second largest establishment of the Department of Atomic Energy after the Bhabha Atomic Research Centre. IGCAR was established at Kalpakkam, 80 KMs south of Chennai [MADRAS], in 1971 with the main goal of performing broad based multidisciplinary programme of scientific research and advanced Engineering, focussed on the development of sodium cooled Fast Breeder Reactor [FBR] technology, in India. ThisFBR forms the part of the second stage of Indian Atomic Energy Programme, which aims at exploring the potential of the country for utilization of the extensive Thorium reserves and providing means to meet the large demands of electrical energy in the 21st century.

In this light, a modest beginning was made by constructing a sodium cooled Fast Breeder Test Reactor [FBTR], with a minimal power of 40 Mwt. The FBTR achieved its first criticality on 18th Oct, 1985 and since then it has been working at its maximum attainable power level of 10.5 MWt with a small core. It is one of the first reactors in the world to use Plutonium Uranium mixed carbide as a driver fuel.

Over these years, theIGCAR has established a large number of research and development facilities covering the entire spectrum of FBR technology related to Sodium Technology, Reactor Engineering, Reactor Physics, Metallurgy and Materials, Chemistry of Fuels and its materials, Fuel Reprocessing, Reactor Safety, Control and Instrumentation, Computer Applications etc., and a strong base has been developed in a variety of disciplines related to this advanced technology.

The experience and expertise gained after the successful operation of FBTR, the Centre has moved towards the design and construction of 500 MWe, Prototype Fast Breeder Reactor [PFBR]. Various research activities in the fields like Structural Mechanics, sodium-water, thermal Hydraulics and flow induced vibration, Component Testing in high temperature sodium environment, reaction, hydraulic development of sodium pumps etc., were pursued and the design was completed. The PFBR is under advanced stage of construction and commissioning by BHAVINI.

As a part of efforts for closing the fuel cycle, a Fast Reactor Fuel Reprocessing Plant is under construction.A 30 KWt, U233 fuelled mini reactor [KAMINI] has been made operational for neutron radiography, neutron activation analysis etc.,

IGCAR utilizes its expertise and resources in enhancing its standing as a leading Centre of research in various branches of basic, applied and engineering sciences that have a bearing on Nuclear Technology like Structural Mechanics, Heat and Mass Transfer, Material Science, Fabrication Processes, Non-Destructive Testing, Chemical sensors, High temperature thermodynamics, Radiation Physics, Computer science etc.

The IGCAR not only works in fields of nuclear technology, but also has credentials as a leader of research in various frontier and topical subjects like Quasicrystals, SQUID fabrication programs, exopolymers and experimental simulation of condensed matter using colloidsOxide superconductors, Nano-structures, clusters, etc.,

The expertise and facilities of IGCAR has been utilised into other vital sectors such as Defence, Space and other industries of India in order to develop techniques for reliable solutions to specialized problems.the centre has also collaborated with educational and R & D institutes like Indian Institutes of Technology, Indian Institute of Science, Pilani, Regional Engineering Colleges, National Research Laboratories, Public Units and Institutes abroad.

Centre For Advanced Technology (Indore)

The Raja Ramanna Centre for Advanced Technology is a unit of Department of Atomic Energy, Government of India, engaged in R&D in non-nuclear front-line research areas of lasers, particle accelerators and related technologies.

Variable Energy Cyclotron Centre

It is a research and development unit of the Department of Atomic Energy. The centre is located in Kolkata, and involved in performance of research in basic and applied nuclear sciences along with development of the latest nuclear particle accelerators. It has a collaboration with the CERN (EUROPE).

Atomic Minerals Directorate

The Directorate, mainly involved in policy and programmes related to Exploration and Research, is the oldest unit of the Department of Atomic Energy (DAE). AMD was created on July 29, 1949 as 'Rare Minerals Survey Unit' headquartered in New Delhi, Under the Atomic Energy Act, passed by the Govt. of India on April 15, 1948 and which was followed by the creation of the Atomic Energy Commission (AEC) in 1948. In the beginning it was named as 'Raw Materials Division' and then later on called 'Atomic Minerals Division' in 1958. The headquarters of AMD were later shifted to Hyderabad in1974.

In keeping with its growing stature as one of the country's leading scientific organizations involved in multi-disciplinary and multi-faceted exploration-cum-analytical-cum research activities, the 'Division' was rechristened as a 'Directorate' on July 29, 1998 on the eve of its stepping into the 'Golden Jubilee' Year.

The operations of AMD started on October 3, 1950 with a nucleus of 17 Geoscientists which has grown to 2354 personnel by 2016. The principal mandate of the unit was to carry out geological exploration and discover mineral deposits required for the Atomic Energy power program of the country.

7.19 MISCELLANEOUS

1. ISOTOPES

- It is defined as variants of a particular element where these variants will have the **same number of protons but differ in the number of neutrons in the atom.**
- Due to the unequal numbers of neutrons, the isotopes of elements usually have a **different mass.**
- Generally, elements which have odd atomic numbers will have one or two stable isotopes whereas elements with even atomic numbers will mostly have three or more stable isotopes. However, there are also exceptions like carbon, helium, and beryllium.
- An isotope is usually denoted or identified by the name of the particular element at the beginning, which is followed by a hyphen and the mass number.
- Some common examples that can be cited are the isotopes of hydrogen and carbon. Talking about the element Hydrogen, it has three stable isotopes, namely protium, deuterium, and tritium.

- These isotopes have the same number of protons, but a different number of neutrons wherein protium has zero, deuterium has one and tritium has two.
- Looking at carbon, it also has three isotopes, namely Carbon-12, Carbon-13, and Carbon-14. The numbers 12, 13, and 14 are the isotopes' atomic masses. It is to be noted that Carbon-12 is a stable isotope whereas carbon-14 is usually a radioactive isotope.
- Apart from the above-mentioned elements, some other common isotope examples include – Zinc has 21 known isotopes, Tin has 22 isotopes, Neon is a mix of 3 isotopes, natural xenon consists of a mixture of 9 stable isotopes, Nickel has 14 known isotopes.

2. RADIOISOTOPES

- These are radioactive isotopes of an element which can also be defined as atoms that contain an unstable combination of neutrons and protons or having excessive energy in their nucleus.
- Different isotopes of the same element have the same number of protons in their atomic nuclei but differing numbers of neutrons.
- The unstable nucleus of a radioisotope can occur naturally, or as a result of artificially altering the atom. In some cases, a nuclear reactor is used to produce radioisotopes, in others, a cyclotron.
- Nuclear reactors are best-suited to producing neutron-rich radioisotopes, such as molybdenum-99, while cyclotrons are best-suited to producing proton-rich radioisotopes, such as fluorine-18.

One of the most common examples of a naturally-occurring radioisotope is uranium.

<u>Applications Of Radioisotope:</u>

Geological dating: in this radioisotopes are used to determine the age of rocks and minerals.

- Carbon dating: is used to determine the age of archaeological objects such as fossils. By knowing the concentration of C-14
- Agriculture: P-32 is used to study the transportation of minerals and salts,killing pests, causing genetic mutations to produce better strains
- Medical treatment: Co 60 is used for cancerous tumours, I-131 used for detection of the thyroid, Na-24 used to detect problems in blood circulation.

7.20 NUCLEAR AGRICULTURE

Some of the most innovative ways being used to improve agricultural practices involve nuclear technology. Nuclear applications in agriculture rely on the use of isotopes and radiation techniques to combat pests and diseases, increase crop production, protect land and water resources, ensure food safety and authenticity, and increase livestock production.

FAO and the International Atomic Energy Agency (IAEA) have been expanding knowledge and enhancing capacity in this area for over 50 years. And the results have led to some major success stories around the world.

Applications in Agriculture:

Animal productivity and Health	The technologies related to nuclear and its components have made a difference in improving livestock productivity, controlling and preventing animal diseases and protecting the environment.
Improved soil and Water Health	In order to maintain healthy soil and water systems, a number of countries are utilizing nuclear technology, which is paramount in ensuring food security for the growing global population.
Pest Management	The nuclear-derived sterile insect technique (SIT) involves mass-rearing and sterilizing male insects before releasing them over pest-infested areas. This novel technology suppresses and gradually eliminates already established pests and also helps in the prevention of the introduction of invasive species – it is also touted to be safer for the environment and human health than conventional pesticides.

Food Safety	To facilitate the trade of safe food and to combat food fraud, Food safety and quality control systems need to be robust at the national level, which costs the food industry up to USD 15 billion annually. Use of Nuclear technology has been helping national authorities in over 50 countries to improve food safety by tackling the problem of harmful residues and contaminants in food products and to improve their traceability systems with stable isotope analysis.
Emergency Response	Radioactivity is present in everything that surrounds us – from the sun to soil. But should a nuclear incident or emergency happen, an understanding of the movement of radioactivity through the environment becomes crucial to prevent or alleviate the impact on agricultural products.
Climate change Adaptation	The agricultural sector uses nuclear and related technologies to adapt to climate change by increasing resource-use efficiency and productivity in a sustainable way.
Seasonal Famine Prevention	Crop-breeding programmes use nuclear technology to help vulnerable countries ensure food security, adapt to climate change and even to tackle seasonal famine.

7.21 RADIOCARBON DATING

Carbon dating is one of archaeology's mainstream methods for dating organic objects up to 50,000 years old. This method is based on the idea of radiative decay of Carbon-14 isotopes over thousands of years. Through physics, scientists have discovered that radioactive molecules decay at a specific rate dependent on the atomic number and mass of the decaying atoms. This constant can be used to determine the approximate age of the decaying material through the ratio of radioactive isotopes to the estimated initial concentration of these isotopes at the time of the organism's death. Scientists have concluded that very little change has occurred in the ratio of Carbon-12 to Carbon-14 isotopes in the atmosphere, meaning that the relationship between these two should be very similar to how they remain today.

Without radiocarbon dating, "we would still be foundering in a sea of impressions sometimes bred of inspired guesswork, but more often of imaginative speculation". Carbon-14 dating is a revolutionary advancement in the study of the history of our planet. It is, in fact, leading to the "reconstruction of the history of the world". This method of dating allows researchers to learn about past civilizations, changes in the earth, and in the climate.

Different civilizations and religions have different methods of dating. However, carbon-14 dating offers something particularly valuable, called absolute dating, which is the age of the substance before the current time. This means that it may be used and compared to dates anywhere in the world. In fact, it is considered the, “most important development in absolute dating in archaeology and remains the main tool for dating the past 50,000 years”. With this tool, scientists hope to unravel the mysteries of how man developed, when the first man lived, where he went, and create a type of timetable of human life.

Carbon has unique properties that are essential for life on earth. Familiar to us as the black substance in charred wood, as diamonds, and the graphite in "lead" pencils, carbon comes in several forms or isotopes. One less abundant form of carbon has atoms that are 14 times as heavy as hydrogen atoms: carbon-14, or 14C, or radiocarbon.

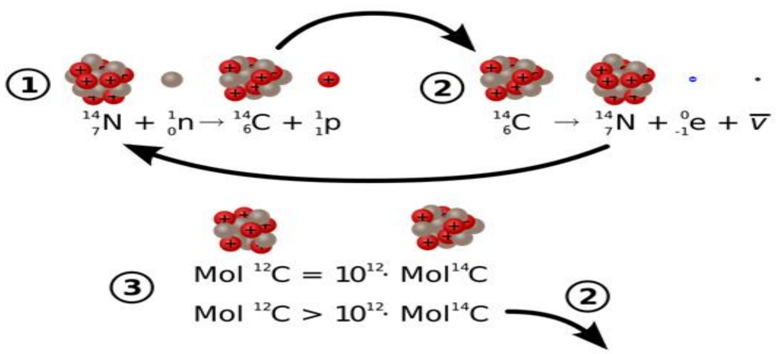


Fig 7.10 :Radiocarbon Dating

Carbon-14 is a radioactive substance. At any given moment carbon-14 is decaying in an object, and if that object is living, it is also being replaced at a steady rate. Carbon- 14 is created when a neutron is excited by a cosmic ray, and then that neutron collides with a nitrogen atom. The carbon isotope is when absorbed by plants through photosynthesis and consumed by animals. Due to the way the sunlight reacts with the atmosphere, it is also taken in by respiration.

7.22 RADIOACTIVITY AND FOOD PRESERVATION

For the preservation of certain foods, the effects of radiation on cells of living or vegetable matter are used, which are effective in destroying microorganisms and parasites

The action of gamma rays radiation, emitted for instance by a cobalt-60 source, leads to ruptures of chemical bonds in their interaction with the matter of living organisms. This process helps in an efficient and reliable elimination of bacteria, fungi and parasites in food. The radioactive treatments are generally more effective since the penetrating power of gamma rays ensures that all points of the product are actually processed.

However, the efficacy are dose dependent. The doses used for preservation and sterilization are adapted to their purpose. The scale of these doses is of course not the same as those applied to humans. For example, we take as low a dose of 50 to 100 grays (Gy), whereas such a dose is considered high in the case of radiotherapy of a cancer and it could be dangerous or harmful if applied non-locally to the whole body.

The low dose irradiation inhibits germination, contributes to deworming of grain and fruit and slows down physiological processes of decomposition. Potatoes, onions, shallots are irradiated to inhibit germination so they are conserved longer. In order to slow down the maturity, the Strawberries and tomatoes get the same treatment. Spices and dried vegetables are also treated to destroy microorganisms.

At moderate dose, we get an extension in time of food preservation by irradiation at medium dose and at higher dose industrial sterilization of meat, spices, and foods prepared by irradiation.

Rays leave no radioactive residues in the product. If they disrupt atoms and molecules, they do not attack the nucleus. Radiation is just energy that passes through food, destroying bacteria and other microorganisms, and then dissipates. The only residue is a small amount of molecules that have been affected in the food by the passage of energy.

7.23 INDIA'S NUCLEAR TEST

Operation Smiling Buddha was the codename assigned for India's first successful nuclear bomb test which was carried out on 18 May 1974. The 15-kiloton plutonium device was caused to explode on the army base, Pokhran Test Range, in Rajasthan by the Indian Army under the supervision of several renowned army officials. The yield of the device is believed to be around 8-12 Kilotons of TNT.

India conducted its first successful test of a nuclear bomb on 18 May 1974 at Pokhran. The secret operation was called "Smiling Buddha" and the current MEA nomenclature for the exercise is Pokhran-I.

CONTROLLED THERMONUCLEAR FUSION

The thermonuclear reaction is the fusion of two light atomic nuclei into a single heavier nucleus by a collision of the two interacting particles with high temperature as a consequence of which a large amount of energy is released. Thermonuclear fusion refers to nuclear fusion reactions which take place at extremely high temperatures (example: reactions in the sun). The energy produced here is extremely high but such reactions cannot be controlled. If we are able to achieve conditions where such a reaction can take place while controlling its rate, then we can achieve what is called the controlled thermonuclear fusion.

In an uncontrolled state, these types of reactions give rise to destructive forces. The hydrogen bomb is an example of an uncontrolled fusion reaction. Another differentiating factor between controlled and uncontrolled fusion reactions is that, since conditions are unpredictable in an uncontrolled reaction, they can't be tapped for any use.

Another issue to consider in a controlled thermonuclear reaction is about containing it.The temperature of the hot plasma is so high that it cannot be in contact with any material.

NEUTRON BOMB

This type of bomb is generally an enhanced radiation weapon (ERW) which is a low yield Thermonuclear weapon and is designed for maximization of lethal Neutron Radiation in the immediate vicinity of the blast while the physical power of the blast is minimized.

INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR (ITER)

- Nicknamed as ‘miniature sun’, ITER is the largest plasma based fusion reactor ever built.
- It is the costliest technological project of the 21st century with an estimated construction cost of $25 Billion.
- The project site is located in Cadarache, Southern France.
- The term ‘Thermonuclear’ indicates the nuclear fusion reaction.
- ITER will be two times the size of the largest fusion reactor present and the chamber volume will be 10 times the present one.

Timeline of ITER Project

- 1988: The Project was initiated and conceptual design studies ran between 1988-90
- 2005: India joined the project as one of the 7 major partners.
- 2013: Construction of the ITER Tokamak Complex was started.
- 2019: 66% of the construction has been completed.
- 2025: Commissioning and initiation of plasma experiments is expected.

International Collaboration in the Project

- ITER is a collaborative project of thousands of scientists and engineers from 35 countries.
- There are seven major partners; India, U.S.A, E.U, Russia, China, Japan, and South Korea.
- These 7 partners constitute about 50% of the world population and about 85% of world GDP.
- EU alone will bear 45% of the estimated construction cost of $25 Billion while the other 6 countries will contribute 9% each.
- Further, specific tasks and components are assigned to each country.

India’s Contributions to ITER

- 17500 Cr. has already been committed by India, amounting to almost 10% of the overall cost of construction, operation and decommissioning.
- India has also provided a Cryostat, the world’s largest refrigerator, weighing around 3800 tons and made with stainless steel.

- It will cover the entire structure and keep the magnetic components at a very low temperature (less than -200OC) for maintaining the superconductivity of magnets.
- It was built by L&T Ltd. in Gujarat.
- India is also assigned with the development of critical components such as:
    - Cooling water
    - Vessel in-wall shielding blocks.
    - Radio frequency heating source.
    - Diagnostic neutral beam system, etc.
    - The Institute of Plasma Research (IPR) at Ahmedabad will oversee the technological commitments of India.
    - Around 100 Indian scientists are also involved in the project.
    - Prime Minister Narendra Modi recently visited the project site and also held discussions with French President Emmanuel Macron.

Benefits to India from ITER:

Being a major partner in the project, would help India to accelerate towards the goal of building a fusion reactor, much earlier than the original deadline of 2035. Moreover, working on the project would be an enriching experience for our scientific community as well as industry.

Having become a full partner, India will be involved in the manufacturing of key components like cryostat vessels, cryogenic lines and distribution systems. Since these components will be manufactured in India using cutting -edge technology, it would be a great experience for both the manufacturers as well as the research programmes for our own national fusion projects.

Results of the experiments and Intellectual Property Rights generated during it will be shared with all the partner countries, including India, which will benefit its regime. Along with it, in the long run, the project would facilitate development and growth of Fusion technology In India which will be effective in meeting the energy demand of the Country besides being a clean source. Thus, not only will it reduce dependency on fossil fuels but will also cater to India's quest for SUSTAINABLE DEVELOPMENT.

7.24 INDIA’S NUCLEAR DOCTRINE

The Nuclear Doctrine of India is based on the principle that India will only use a nuclear weapon in retaliation to a country’s attempt of attacking India, its states or its army with a nuclear weapon. Nuclear Doctrine, in general, is how a country with a nuclear weapon uses the weapon in peace and at the time of war.

The Nuclear Doctrine of India is based on three main pillars. The three pillars of India's nuclear doctrine are as follows:

- No first use
- Credible minimum deterrence
- Civilian control (NCA)

All other components of the doctrine such as survivability strategic(the ability of personnel, equipment, and systems to survive the effects of **nuclear** weapons) trend, punitive retaliation in rapid response and shift from peacetime deployment to fully employable forces in the shortest possible time are all strict mathematical derivations of the above three basic principles.

Indian's nuclear doctrine is the most responsible doctrine which aims at providing the minimum credible deterrent. It is a consensus document and does not restrict the country from exercising its nuclear weapon options in any manner. It offers complete elasticity in deciding the number of nuclear weapons India should possess.