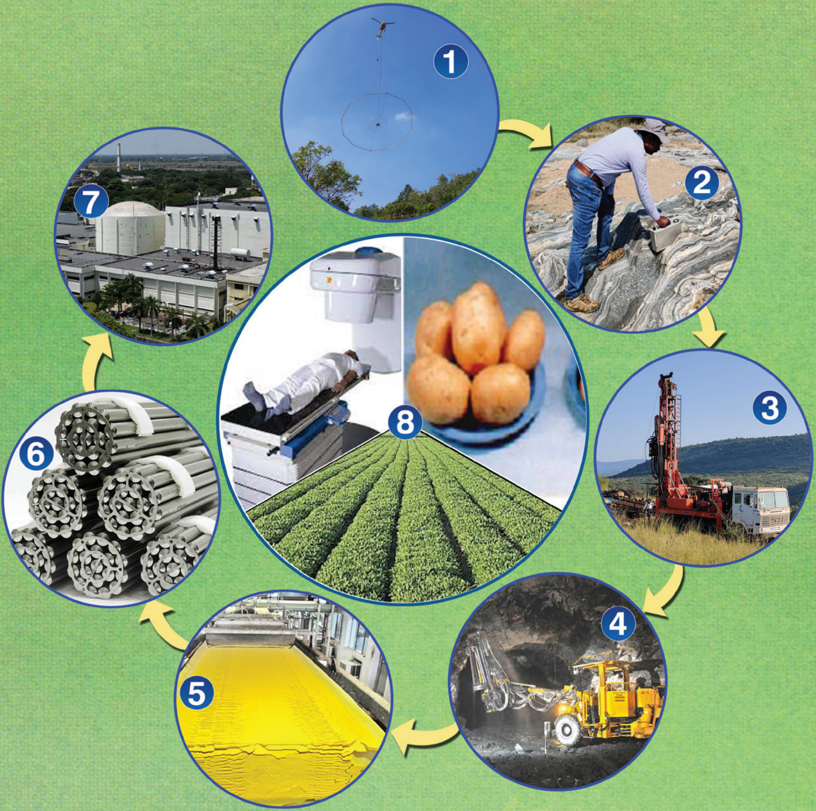
Nuclear Energy

A Reliable Option for Clean and Green Energy



Editor-in-Chief

Dr. D.K. Sinha

Director, AMD

Atomic Minerals Directorate for Exploration and Research

Department of Atomic Energy

August, 2022

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A Reliable Option for Clean and Green Energy

TECHNOLOGIES FOR
NEW INDIA@75
आज़ादी का अमृत महोत्सव

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PREFACE

It is a well-known fact that our country is aiming to achieve net zero emission by 2070. In the process, it is imperative that we reach the projected 500GW non-fossil fuel energy capacity and reduction of total projected carbon emission by one billion tonne by the year 2030. In order to achieve this target there is an urgent need for increasing the electricity production using a mix of renewable as well as long term clean & green non-fossil fuel sources. Power generation by solar, wind and hydro power plants has many constraints, therefore, other reliable green energy sources are required to be harnessed to the optimum levels. Nuclear energy is one such reliable source which can play a significant role in meeting the target of net zero emission. In this context, it is imperative that the nuclear fuel resources are explored and exploited for unhindered fuel supply to the nuclear power plants. Unfortunately, due to certain misconceptions about nuclear energy in the mindset of a small proportion of the populace, our country is witnessing opposition to exploration and mining of uranium by some sections of the society in certain parts of the country.

In view of the above, the Atomic Minerals Directorate for Exploration and Research (AMD) decided to bring out a booklet on 'Nuclear Energy- A Reliable Option For Clean & Green Energy' on the occasion of 'Azadi ka Amrit Mahotsav' to bring about a positive change in the society at large by allaying the apprehensions based on misinformation related to the after-effects of exploration and mining of uranium. The booklet contains chapters on Energy, Power Generation, Nuclear Fuel Cycle, Radiation, Mineral Exploration and Mining for uranium and Applications of Radiation Technologies for Societal Benefits. The last chapter showcases the advantages and benefits of nuclear energy in the fields of healthcare, agriculture, food preservation, waste management, etc. which have benefitted the society by creating better living conditions and reducing the economic burden.

I am hopeful that the booklet will gain wide readership and find a place in the libraries of prominent institutions of the country. In the 75th year of Independence of our country, this booklet is a small contribution by AMD to take India forward in the path of progress and prosperity to achieve 'Atmanirbharta' in the field of nuclear energy.

Dr. Deepak Kumar Sinha
Director, AMD

Nuclear Energy

A Reliable Option for Clean and Green Energy

CONTENTS

1 "INTRODUCTION"

Man has since ages been on search for energy as a life sustaining force and a necessity that is required to support his every walk of life. It has been a continuing journey of finding energy resources starting right from fire wood, fossil fuels ... to thermal electricity, hydel electricity, nuclear power to other alternate resources.

Presently, the major sources of energy are coal and other fossil fuels all over the world. These fuels account for release of enormous quantities of pollutants into the atmosphere. As these are non-renewable and depleting fast, there is a need to exploit other natural resources in view of increasing demand for electricity. The importance of nuclear energy becomes all the more relevant in view of its environmental friendly and associated societal benefits of the by-products.

For producing nuclear power, uranium is required, which exists in nature chiefly as the uranium mineral, uraninite and some other minerals in different rocks. Hence, the production of nuclear power starts from mineral exploration and mining for uranium. The task of uranium mineral exploration is carried out across the country only by the Atomic Minerals Directorate for Exploration and Research (AMD), a constituent unit of Department of Atomic Energy (DAE). The work involves survey, exploration and evaluation of resources of uranium and other atomic minerals in various parts of the country. Major areas of uranium resources are located in the states of Jharkhand, Meghalaya, Andhra Pradesh - Telangana (Kadapa and Nalgonda districts and parts of Nallamala forest areas) Rajasthan, and Madhya Pradesh.

The favourable target areas are initially identified based on interpretation of photogeological and remote sensing data and available geological information. This is followed by airborne/ heliborne geophysical survey using scientifically advanced techniques to collect data over larger areas. The potential areas delineated from the above survey are taken up for different ground surveys using latest scientific instruments. In areas where presence of uranium is indicated, drilling is taken up to establish the depth, extent and nature of host rock. The collected samples are tested in various laboratories of AMD for identification of minerals and characterisation. In all these activities including surveys, exploratory work including drilling and analysis of samples, disposal of samples, AMD follows the practices prescribed by International Atomic Energy Agency (IAEA) and Atomic Energy Regulatory Board (AERB). More details on the above activities are presented in the following chapters.

Uranium mining is carried out by Uranium Corporation of India Limited (UCIL), a public sector Unit under DAE, in areas where Uranium reserves of economic grade are established. The mining is carried out by following all the guidelines of IAEA and safety standards as stipulated by AERB. The scientists from both the organizations through various public outreach programmes, publications, exhibitions are always available to provide authentic information to the public on all the issues concerned.

The uranium ore obtained from the mine is sent to uranium mill where the ore is crushed, treated through acid/alkali leaching method to prepare yellow cake containing uranium. This is further processed in the Nuclear Fuel Complex (NFC) where pure uranium oxide is made in the form of pellets and cladded in zircalloy tubes, fabricated into fuel bundles and sent to nuclear power plant for production of electricity. The entire process is carried out as per IAEA and AERB guidelines giving no room for any complacency in following stipulated safety norms.

In the states of Andhra Pradesh and Telangana, investigations for finding uranium reserves are going on. Some of the localities fall under Nallamala forest areas. There are some unfound fears about the uranium investigations in the minds of the people due to misinformation and misconceptions prevalent among a section of the people. Some of the fears spread are- that the tribal culture and living style will be affected, lands become uncultivable, danger of miscarriages, increasing incidences of malignancy, still births, physical deformities, etc.

The spread of such fears has made the public more apprehensive to the extent that they are opposing any survey and exploration activity in the entire area.

The present publication is meant exclusively for the general public to make them understand things as they are based on authentic information provided on all the activities of AMD and other constituent units of DAE. The objective of the Department is to bring awareness among the public to realize the importance of nuclear energy and all related activities. Besides, the resultant technologies have humongous benefits to the society, which improves the quality of life of common man. The availability of electricity is considered as a true index of the prosperity of the nation.

This publication of the Department will help the public to allay the misconceptions. The Department assures to provide more information as and when required and clarify all doubts on the issues concerned.

Let us all be aware of the facts – let us move forward without fear.

2 "ENERGY FOR DEVELOPMENT"

Energy is crucial to human survival. From the time we wake up to the time we go to sleep at night, energy plays an important role in our lives. Is it possible to do any task without energy? Almost everything we see around us, the clothes we wear, the food we eat, the house we live in, the paper we write on, the vehicles we drive, all need energy. Energy provides comfort, helps in increasing productivity and allows us to live the way we want to.

Each major leap in human evolution has seen a manifold increase in energy consumption. The industrial revolution has caused a steep jump in per capita energy consumption. In prehistory, the dominant source of energy was muscular. Later, energy was derived from machines that used fossil fuels like coal. In industrial age, steam engines were used. Then came electricity, which has become the most important form of energy. Now-a-days, the electrical energy has become an essential part of our lives. All electrical appliances in our homes and at our workplaces require electricity. All the industries and factories run on electricity, almost every activity is electricity dependent.

The amount of energy used by any nation is an indicator of its economic growth and development. Access to modern energy services is fundamental to fulfilling basic social needs, driving economic growth and fuelling human development as they have a direct effect on productivity, health, education, safe water, communication services, better access to information and agricultural produce.

Industrially developed nations have higher per capita Gross National Product (GNP) and higher per capita energy consumption. The per capita energy consumption of India (~1300kWh) compared to many developed countries like USA (~4500kWh). Quality of life improves with per capita energy consumption. India should produce far more energy than at present for its growing population.

Increase in energy production and its more efficient utilization will yield rich dividends in terms of improved quality of life and the well-being of people.

Sources of Energy

Energy is sourced from coal, petrol, diesel, kerosene and natural gas. Other sources are hydel, wind, solar, biomass, etc. All the sources of energy can be divided into two categories: non-renewable and renewable. Some of the energy sources can be replenished in a short period of time. Such energy sources are referred to as 'renewable' energy sources. Whereas, the energy sources that we are using up and cannot be generated are called non-renewable energy sources.

Non-renewable energy sources

The petrol and diesel extracted from crude oil are commonly used to run different kinds of vehicles. Similarly, kerosene and natural gas are used as fuels for cooking and lighting. Coal is used for electricity generation. Crude oil, coal and natural gas occur in limited and exhaustible quantities. They cannot be regenerated and hence are called non-renewable sources of energy. It is a fact that at present we get most of our energy from non-renewable energy sources which include fossil fuels such as coal, crude oil and natural gas. Over 85% of our energy demands are met by the fossil fuels. Looking at the present and future energy requirements, it is expected that our oil and natural gas reserves as well as coal reserves will not last for long time. So, we must use these sources judicially.

Most of the coal available in the country is low grade - high in ash and sulphur content. Also, coal based thermal plants contribute substantially to greenhouse gases and consequently to global warming-a-cause of much worldwide concern. Besides, it is important to conserve coal reserves for non-electricity applications like steel and allied industries.

Renewable energy sources

There are several alternative and renewable sources of energy which are generally environmental friendly. Wind, sunlight, geothermal, sea waves and biomass are some such possible sources of energy. These sources will help in reducing pollutants, greenhouse gases and toxins that are by-products of fossil fuels. They also help preserve the delicate ecological balance of earth; help conserve the non-renewable energy sources.

Indian scenario

In India, thermal power accounts for 59.7% of the total installed electrical capacity, hydro power accounts for 11.8% and renewable energy 23.1%. Nuclear power contributes about 1.7% of the total capacity at present (Fig. 1).

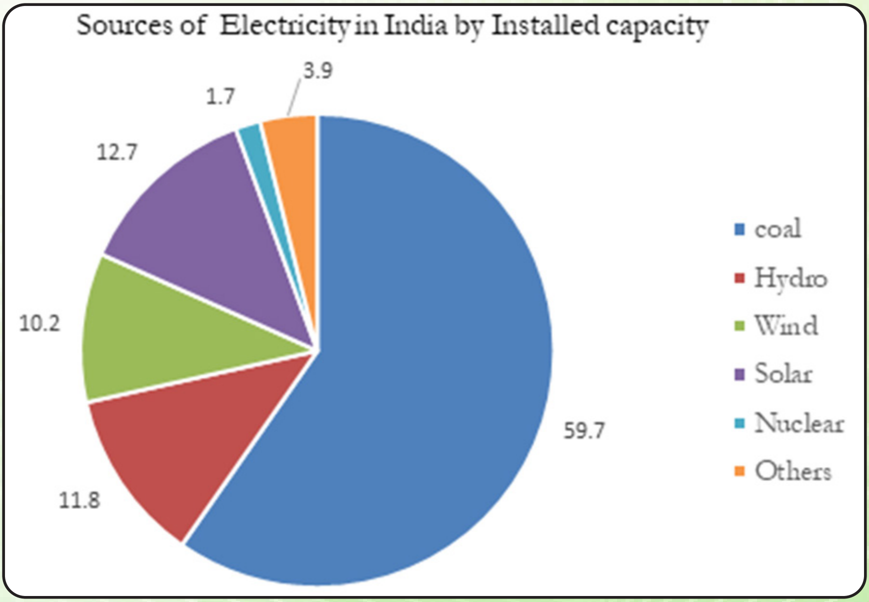


Fig-1: Sources of Electricity in India by Installed capacity (Source: Ministry of Power website)

The per capita electrical energy consumption is a good indicator of a country's development and the quality of life of its people. For India, this is nearly 1300 kWh. Our per capita electrical energy consumption is lower than the world average (about 3260 kWh). To achieve this target, a balanced strategy needs to be formulated.

To sum up, energy is required for survival of humans. Energy is part of our everyday life. It is not possible to live without energy. Amount of energy used is an indicator of Country's development and economic growth.

3 “Power Generation”

Power plants generate electricity. There are various types of power plants, most important are- thermal, hydroelectric, nuclear, solar and wind. In all these power plants one form of energy is converted into another form to finally produce electrical energy. Each of these power plants has its own set of features, requirements, advantages and constraints. They can be compared on the basis of several parameters. But in all the power plants the blades of a turbine are rotated and through a generator electricity is produced. The salient points are given below:

Thermal Power Plant

Almost two third of electricity requirement of the world is fulfilled by thermal power plants (or thermal power stations). In these power plants, fossil fuels (e.g. coal, natural gas and oil) are burnt to heat water to produce steam, which is in turn used to run a turbine to produce electricity. Majority of thermal power plants use coal as their primary fuel. They require a large space due to coal storage, turbine, boiler and other auxiliaries. They are generally located at a site where coal, water and transportation facilities are available easily. A huge amount of heat is lost in various stages of the plant. That is why the efficiency of thermal plants is quite low. Thermal efficiency of modern thermal power stations is about 30%. It means, if 100 calories of heat are produced by coal combustion, the mechanical energy equivalent of 30 calories will be available at the turbine shaft.

Coal has limited availability and is depleting fast. In fact, we are already importing part of our coal requirement. Burning coal produces large amounts of CO_2 and fly ash pollution which contribute to global warming and lung related health issues. Global warming is causing mean sea level to rise through melting of glaciers and ice sheets worldwide by adding water to the ocean. The ash content of Indian coal is high (25-45%) when compared to that of imported coal (10 – 20%). Impurities are also a cause of concern as they are major source of pollution such as SO_2, which travels on air currents and precipitates as acid rain. Mercury, a toxic element, bio-accumulates and biomagnifies through ecosystems when it travels on air currents and fall as particulate dust or with precipitation elsewhere.

Hydroelectric Power Plant

Hydroelectric power is an important type of renewable energy. Potential energy of water is converted to kinetic (mechanical) energy and the moving water turns the blades of a turbine. The turbine spins and through a generator, electricity is produced. Hydroelectric power plants are located where a large amount of water is available and can be collected easily in a reservoir by constructing a dam. Very large space is required for construction of a huge dam and storage of water. Efficiency of hydroelectric plant is high, about 85% to 90% but production of electricity fluctuates as it is dependent on the availability of water during various seasons. Initial cost of the plant is very high, as construction of a dam and reservoir is expensive. Operational costs are negligible as cost of the fuel is not involved and maintenance is low. Electricity produced from hydroelectric plants is clean and not related to release of any harmful pollutants. But there are many limitations to power generation. Dams cause submergence of forest and agriculture land as well as displacement of people. Hydel power is dependent on rainfall and sufficient supply of water.

Nuclear Power Plant

In Nuclear power plants, atoms are split and the resultant energy is used to heat water to produce steam. Steam turns the blades of a turbine and through a generator electricity is produced. Nuclear power plants requires minimum space compared to other plants of the same capacity. Efficiency is higher than Thermal Power Station. Cost of fuel (uranium) is very low. A small amount of fuel is used, so transportation costs are less. The initial cost of plant may be higher but the running costs is low, as only small amount of fuel is required. Maintenance costs are high when compared to the other plants as skilled engineers are required during the operation of a nuclear reactor. Concerns are expressed as radioactive waste is produced, but the closed fuel cycle adopted in India reprocesses the waste (spent fuel) and most of the waste is again used as fuel by processing, which results only negligible (1%) quantity of nuclear waste.

Solar Power Plant

Solar power plant is based on the conversion of sun radiation into electricity. Mostly, photovoltaic cells/panels are used for generation of electricity. The electricity produced through these panels is in direct form, which has to be converted to alternating form to supply the needs. There is another efficient way to convert sunrays into electricity by using the solar thermal power plants, which utilize energy from the Sun to heat a fluid (mineral oil) to a high temperature. This fluid then transfers its heat to water, which then becomes superheated steam. This steam is then used to turn turbines in a power plant, and this mechanical energy is converted into electricity by a generator. This type of generation is essentially the same as electricity generation that uses fossil fuels, but instead heats steam using sunlight instead of combustion of fossil fuels. Solar thermal power plants represent a type of electricity generation technology that is cleaner than generating electricity by using fossil fuels. Some of the drawbacks of solar power plants include the exceedingly large amount of land, necessary for these plants to operate. As well, the water demand of these plants can also be seen as an issue, as the production of enough steam requires large volumes of water. A final potential impact of the use of large focusing mirrors is the harmful effect these plants have on birds. These require specific site conditions and cannot be operated where power is required on a continuous basis.

Wind power

Wind power is the generation of electricity from wind through turbines. Several factors influence the potential wind resource in an area. The three main factors that influence power output are: wind speed, air density, and blade radius. Wind turbines need to be in areas with a lot of wind on a regular basis, which is more important than having occasional high winds. Wind speed largely determines the amount of electricity generated by a turbine. Higher wind speeds generate more power because stronger winds allow the blades to rotate faster. Turbines are designed to operate within a specific range of wind speeds.

Besides the above main power generation plants, biomass power plants are also one category where wood waste or other waste is burned to produce steam that runs a turbine to produce electricity. These plants also produce air pollution.

From all these details it is to be noted that by burning fuel or splitting atoms water is heated to make steam and the steam or moving water (in case of hydroelectric plant) turns turbine through which the generator produce electricity.

The energy mix of India contains contributions from thermal, hydroelectric, renewable sources and nuclear power plants. Out of these, maximum power is generated by thermal power plants using fossil fuels, mostly coal and gas (~74%) followed by hydroelectric (11%), renewable sources including solar & wind (11%) and nuclear (3%) (as on January 2022, Annual Report, Ministry of Power).

In response to increasing concerns about the effect of anthropogenic greenhouse gases on global climate, Kyoto Protocol adopted a resolution to reduce emissions. Renewable energy is being explored with renewed commitments for addressing challenges such as poverty and global warming.

The 2018 report by the Inter-Governmental Panel on Climate Change (IPCC) warned against climate changes in the coming decades and stressed on severely limiting the operation of coal-fired power plants by 2050 to limit global warming. Coal-based power plants are also a significant contributor to pollutants such as particulate matter (PM), nitrogen oxides (NOx) and sulphur dioxide (SO_2).

Around the world, clear need for new generating capacity with non-fossil fuel plants is being emphasised, both to replace the old fossil fuel units, especially the coal fired ones, which emit a lot of carbon dioxide and to meet increased demand for electricity in many countries.

In the present power production scenario, augmentation of electricity production does not go hand in hand with limiting CO_2 emissions. Solar, wind and nuclear based power has to grow significantly in order to make progress towards emission free power generation. Solar, hydel and wind sectors have potential, but there are limitations. These sources are inherently fluctuating, climate dependent, and uncertain.

Reliable power provides the foundation for modern life. About 60% of power comes from thermal power plants. The power produced by wind and solar power plants are unreliable, and it is difficult to keep electricity supply and demand in balance from these sources. When the thermal power plants are shut due to depletion of resources, it becomes all the more essential that other sources of power generation are harnessed to the optimum levels.

India faces a twin challenges in reducing carbon footprint such as (1) replacing thermal power with renewable energy sources in a phased manner and (2) meeting increased demand for power. The power sector in India accounts for 49 per cent of total CO_2 emissions, compared to the global average of 41 per cent. On the other hand, electricity demand in India is expected to grow rapidly, which makes it crucial for India to urgently adopt cleaner technologies on a large scale and promote sustainable power generation. The coal and oil resources are also depleting at a faster rate and it is speculated that they may not last for more than hundred years. The main challenge being faced in this direction is intermittency of renewable power as renewable energy cannot produce power at all times during the day.

When one hear the words 'Clean Energy' what comes to our mind? Most people immediately think of solar panels or wind turbines but how many of us thought of nuclear energy? Nuclear energy is often left out of conversation despite it being the second largest source of low-carbon electricity in the world behind hydropower. Nuclear energy protects air quality as it is a near zero-emission of harmful air pollutants that contribute acid rain, smog, lung cancer and cardiovascular diseases.

The nuclear technology in India has improved by adopting latest technology and highest level of safety, over five decades of successful operations, since the first nuclear reactor at Tarapur was synchronized to the grid in 1969. Nuclear power plants have several advantages over other power plants. Nuclear energy land footprint is small. Despite producing massive amounts of carbon-free power, nuclear energy produces more electricity on less land than any other clean source. The relative land use requirement for electricity generation by different power plants varies considerably (Fig. 2).

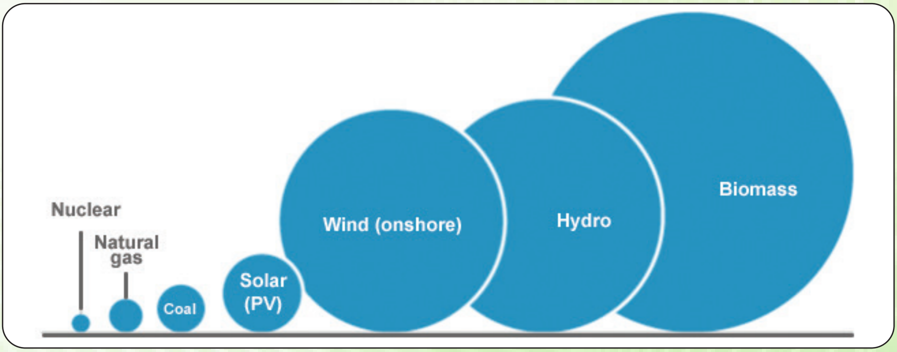


Fig-2: Relative land use (fuel mining and generating footprint) of electricity generation options per unit of electricity (Source: Brook & Bradshaw, 2015 in WNA website)

The materials required for construction of nuclear power plant are also less in comparison to other power generation technologies (Fig.3).

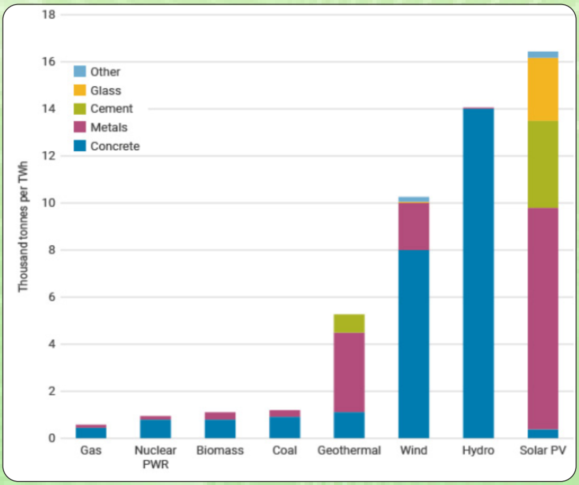
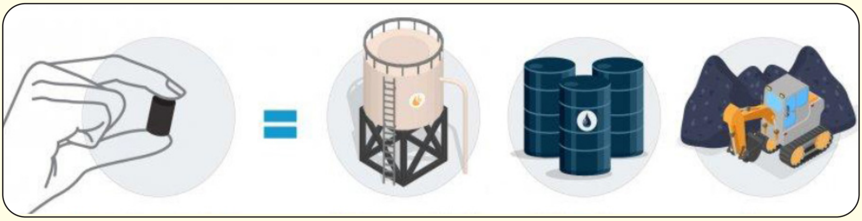


Fig-3: Materials requirements for various electricity generation technologies (Source: US Dept. of Energy)

Nuclear fuel is energy dense (Fig. 4) and energy is produced with minimal waste. One gram of fissionable uranium produces a million times more heat than burning one gram of coal. A nuclear power plant which produces 220MW of electricity, requires about 100 kg of uranium oxide fuel per day i.e., one truck load of fuel per month. In comparison, a coal burning thermal power station of the same capacity would require 6000 tonnes of coal daily i.e., 2 or 3 train loads of coal to be transported every day from the coal mines. The comparison of electricity generated by one kilogram of different fuels is given in Table-1.



1 uranium pellet- the size of little finger tip (~25gm) *4.6 lakh litre of natural gas* *700 litre of oil* *800 kg of coal*

Fig.-4: Comparison of different energy resources
(Source: Modified after US Dept. of Energy)

Table-1: Comparison of electricity generation from different sources

From 1 kg of	Firewood	Coal	Oil	Natural Uranium
Electricity generation	1kwh	3kwh	4kwh	50,000 kwh

A 1000 MWe nuclear power plant requires 20 hectares of land whereas a coal fired plant of same capacity requires 70 hectares of land. It may be noted that a hydroelectric plant of same capacity causes submergence of 2000 – 5000 hectares of land. Fuel consumption and waste generation for 1000 MWe energy by thermal plant and nuclear plant is given in Table-2.

Table-2: Comparison of fuel consumption and waste generated per 1000 MWe power station

1000 MWe station			
Category		**Thermal power plant**	**Nuclear power plant**
Fuel used in tones / year		15,00,000	250
Wastes			
(in tones / year)	Ash	6,25,000	Nil
	CO_2	65,00,000	Nil
	SO_2	9,000	Nil
	NO_X	4,500	Nil

Further, India reprocesses the spent fuel and use the major part of it again to fuel the reactors, which even the developed countries like United States are not doing. The nuclear power plants are the most reliable energy source as they run 24 hours a day, 7 days a week and requires least maintenance as compared to the other sources of energy.

The uses of nuclear technology extends beyond the provision of low carbon energy. It assists doctors in their diagnosis and treatment of patients, extends the shelf-life of agricultural yield and powers missions to explore space. These varied uses position nuclear technologies at the heart of the world's efforts to achieve sustainable development. At the end of the day, without any doubt everyone will accept that nuclear energy supports national security. With these additional benefits, nuclear power poses to be a prominent reliable alternative for thermal power plants to lead the race for fulfilment of energy requirements of the world and especially our nation.

The human evolution is linked to the availability and use of energy. From the early use of fire and animal power that improved lives, to the present world with use of electricity and cleaner sustainable fuels for a multitude of purposes - energy has been the enabler of development. Energy presents a fundamental need ranging from, but not limited to, the essential services of cooking, heating, cooling, lighting, mobility, and operation of appliances, to information and communications technology, and machines in every sector of every country. The lack of access to reliable and clean energy supplies is now considered as a major barrier to improve human wellbeing around the globe.

The World Bank in a report said that despite making remarkable progress in electricity distribution over the years, India still faces challenges in meeting its growing demand for power and reliable supply still remains low in the country. Citing projections from the International Energy Agency, the World Bank said that the demand for electricity in India will almost triple between 2018 and 2040 in view of the growing population, rapid urbanisation and an economy that is expected to grow at an average of 7 per cent every year. All these clearly depict the significance of energy in the development of our country. The situation can be improved by increasing the share of nuclear energy.

4 "Nuclear Fuel Cycle"

The nuclear fuel cycle refers to all the activities that occur in the production of nuclear energy. Producing nuclear energy requires more than nuclear reactor equipment which produce electricity from the heat created by nuclear fission. The process includes identifying the resources, ore mining & processing, fuel fabrication, electricity generation, waste management and disposal, and finally decontamination and decommissioning of facilities. All steps in the process must be specified, because each stage involves different technical, economic, safety, and environmental consequences. Nuclear Fuel cycles can be broadly categorized into "open" and "closed." In the open or once through fuel cycle, the spent fuel discharged from the reactor is treated as waste. In the closed fuel cycle, the spent fuel discharged from the reactor is reprocessed and the products are separated into uranium (U) and plutonium (Pu), suitable for fabrication into oxide fuel or mixed oxide fuel (MOX) for recycle back into a reactor.

Open fuel cycle is expected to have an advantage in terms of cost, compared to the closed cycle, since no reprocessing and separation of actinides are involved. Closed cycles have an advantage over the open cycle in terms of maximum resource utilization which in turn is more economical as the requirement of fresh uranium fuel is reduced and full potential of nuclear power is exploited. Some argue that closed cycles also have an advantage for long-term waste disposal, since long-lived actinides can be separated from the fission products and transmuted in a reactor. The entire nuclear fuel cycle is depicted in figure-5. A brief description of the stages involved in Nuclear Fuel Cycle are given below.

The nuclear fuel cycle consists of 'front end' steps starting from identification of resources to prepare uranium fuel bundles for use in reactors to generate electricity and 'back end' steps involving safe management of spent nuclear fuel including reprocessing and recycling and disposal.

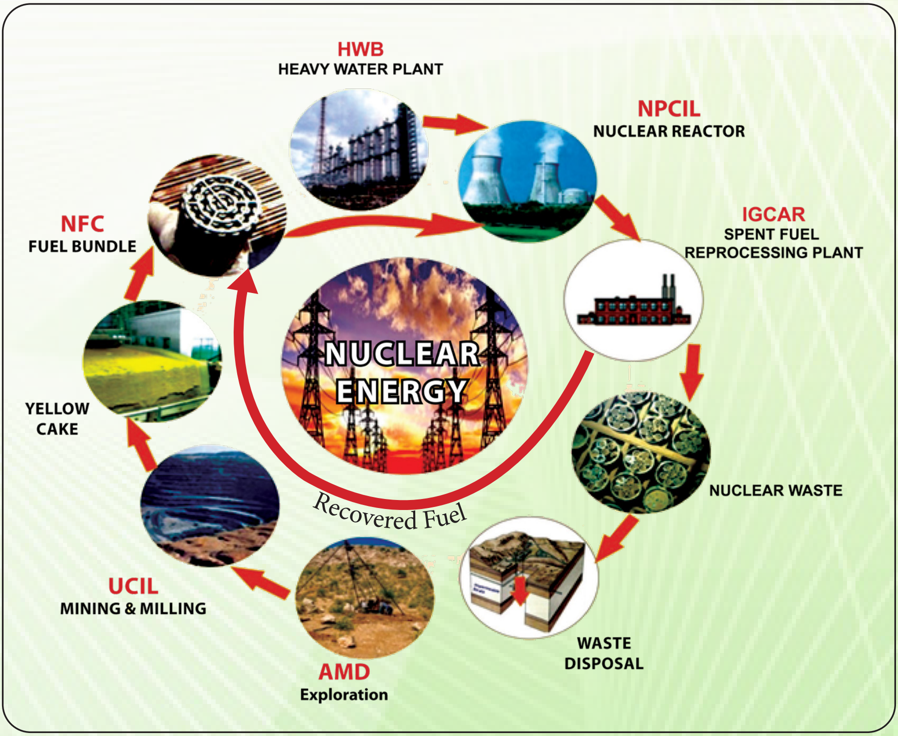


Fig-5: Nuclear Fuel Cycle

Front end of Nuclear Fuel Cycle

Exploration

The nuclear fuel cycle starts with exploration for uranium and identification of viable resources for extraction. A variety of techniques are used, such as geological mapping, airborne/ heliborne geophysical surveys, ground geological, geophysical and geochemical surveys to cover larger areas in search for uranium. During all these phases of exploration, rock chip, soil and water (ground and surface) samples are collected for studies in laboratories besides the geological mapping at different scales. Once a target is identified, it will be explored by drilling boreholes. After uranium deposit is proved, it is taken up for commercial mining.

Mining and Processing of ore

Mining and processing of uranium ore has a significant role in nuclear fuel cycle. It fulfills the requirement of uranium for the nuclear reactors. Uranium mining is the process of extraction of uranium ore from the ground. Open pit mining and underground mining are usually employed for extraction of uranium ore. Open pit mining is employed where ore bodies lie close to the surface. In case of deeper ore bodies, underground mining is employed which involves construction of access shafts and tunnels but with less waste rock removed and less environmental impact.

In India, six underground mines (Bagjata, Jaduguda, Bhatin, Narwapahar, Turamdih and Mohuldih) and one open pit mine (Banduhurang) are operating in the State of Jharkhand for mining of uranium ore. Ore produced from these mines are processed in two processing plants located at Jaduguda and Turamdih. One underground mine and processing plant is also in operation at Tummalapalle in Andhra Pradesh.

After mining of uranium ore, it is transported to a mill, where it is crushed and chemically treated by addition of either acid or alkali, to leach out the uranium. The remaining crushed rock, called 'tailings', is appropriately disposed of. After leaching of uranium from ore body, the uranium bearing leach liquor is purified and concentrated using either ion exchange or solvent extraction method. The uranium is then precipitated from this concentrated liquor using magnesia, soda, ammonia or hydrogen peroxide and the final product is called 'yellow cake'. The yellow cake is washed thoroughly followed by drying and securely packed in drums and sent to fuel fabrication plant for further processing and making fuel assemblies.

During processing of uranium ore, two types of wastes are generated. They are (1) the leach liquor depleted in uranium from purification (either ion exchange or solvent extraction) unit after recovery of uranium, and (2) the filtered solids depleted in uranium after filtration of the leached slurry. Both are neutralized with limestone and lime slurry to precipitate the remaining radionuclides along with heavy metals like manganese, iron, copper, etc. The neutralized slurry is classified and the coarse fractions are pumped back to the mines for back filling of the voids. The fine particles are pumped to the tailing pond, where the slime settles and the clear liquor is sent to the effluent treatment plant for further processing.

Mining and transportation of uranium ore up to the processing plant for yellow cake strictly comply with various AERB safety guidelines.

Nuclear Fuel Fabrication

Fuel fabrication plant is a unique facility created for manufacture of natural uranium fuel assemblies for nuclear reactors. It involves conversion of yellow cake into uranium dioxide (UO_2) in the form of pellets. These pellets are loaded into zircalloy tubes to form fuel elements. Many such fuel elements make up a fuel assembly. Fuel assemblies are designed to allow transfer of heat to the water, which flows through them carrying away the heat from the fuel elements during reactor operation.

Electricity generation

A nuclear power plant is much like any gas or coal fired power plant. The significant difference between fossil fuel and nuclear power plants is the source of heat. In a fossil fuel plant, the heat is produced by burning gas or coal. In a nuclear plant, the heat is generated by the fission of uranium in the nuclear fuel assemblies. When the nucleus of an atom, for example, ^{235}U absorbs a neutron, it splits into fragments, giving off energy as heat and 2-3 neutrons are released which sustain the chain reaction in the reactor. This chain reaction is controlled to produce exactly the desired amount of energy. This energy is used to convert water into steam to drive turbines and to run generators, producing the electrical energy.

Fission of a single atom of uranium yields energy equal to 200 MeV (million electron volts) in comparison to only 4eV in the oxidation of one carbon atom. Therefore, on equal weight basis, the total energy from the nuclear fission of 1 tonne of uranium is as much as that produced from 2.5 million tonnes of coal combustion.

Back end of nuclear fuel cycle

The steps involved in back end of the nuclear fuel cycle depend on type of nuclear fuel cycle. In open fuel cycle, direct disposal of spent fuel (nuclear waste) is the only step involved whereas in case of closed fuel cycle, storage of spent fuel, reprocessing, recycling and finally disposal of nuclear waste are involved. It is a tribute to the foresightedness of Dr. Homi J. Bhabha that India should adopt closed fuel cycle for optimum utilisation of uranium resources. Closing fuel cycle by reprocessing and recycling fissile & fertile material back into reactor system helps in exploiting the full potential of nuclear power as well as recovery of valuable radionuclides, followed by significant reduction of waste volume as compared to an open cycle.

Spent fuel storage

After useful life of fuel assemblies, they are removed from the nuclear reactor. The spent fuel assemblies removed from the reactor are radioactive as a result of nuclear fission. Because of this radioactivity, the fuel assembly is handled by remote controlled fuel assembly loading / unloading machine to transfer it for storage in a water-filled pool inside the station for cooling. After few years of storage under water, the spent fuel assemblies are taken in shielded containers to the reprocessing plant.

Spent Fuel Reprocessing

The spent fuel discharged from the reactor is known as Spent Nuclear Fuel (SNF) and it contains uranium, plutonium and high level radioactive fission products. In reprocessing plant, operated by remote control through heavy shielding, three main product streams are separated from SNF. They are (1) depleted uranium (about 98%) stored for recycling in fast breeder reactor, (2) the plutonium (about 0.4%) formed when neutrons are absorbed by atoms of non-fissionable uranium. This is very valuable and can be used as fuel for fast reactors, and (3) Mixed long-lived radioactive fission products (about 1%). High level waste (<0.5%) generated is vitrified, or converted into a glass (natural uranium is available in silicate rocks, so the nuclear waste is also converted into glass form), to be disposed of in a high level waste disposal facility.

Nuclear Waste Management

Nuclear (Radioactive) waste management refers to the safe treatment, storage and disposal of liquid, solid and gas discharge from nuclear industry operations with the goal of protecting people and the environment. So, management of nuclear waste has been accorded high priority right from the inception of nuclear energy programme in India.

Nuclear waste is generated in the form of gaseous, liquid and solid during operation & maintenance activities of nuclear fuel cycle facilities. Gaseous waste is treated at the source of generation using the techniques such as absorption-chemical scrubbing, adsorption on activated charcoal and filtration by High Efficiency Particulate Air (HEPA) filters. Liquid waste streams are treated by various techniques, such as filtration, adsorption, chemical treatment, evaporation, ion exchange, reverse osmosis, etc. depending upon the nature, volume & radioactivity content. The radioactive solid waste generated is segregated and the volume is reduced prior to its disposal in specially constructed engineered disposal structures such as stone lined trenches, reinforced concrete trenches and tile holes for ensuring effective containment of the radioactivity till the radionuclide decays to low level.

High Level Liquid Waste (HLLW) generated during reprocessing of spent fuel contains most of the radioactivity generated in entire nuclear fuel cycle. The HLLW is immobilized into an inert Sodium Boro-Silicate glass matrix through a process, called vitrification. The vitrified waste is stored for an interim period in an air cooled vault to facilitate the dissipation of heat generated during decay of radioactivity, prior to its eventual disposal in geological repository. Vitrification of HLLW is a complex process and very few countries in the world could master this technology and India is one among them.

Recovery of valuable radioisotopes from Nuclear Waste

Before final disposal of HLLW into deep geological repositories, the useful radio-isotopes such as ^{137}Cs, ^{90}Sr, ^{106}Ru (having various medical and industrial applications) present in HLLW are recovered. The energy associated with these isotopes is used for blood irradiation, food preservation, and therapeutic applications. Separation and recovery of useful isotopes from radioactive waste and their deployment for societal application makes the nuclear waste as an important resource.

Conclusion

The closed nuclear fuel cycle adopted by India encompasses the entire gamut of activities starting from exploration of uranium minerals to fabrication of fuel elements, reprocessing of spent fuel and disposal of nuclear waste into deep geological repositories. With the integrated approach, India is successful in reduction of nuclear waste volume by utilizing significant fraction of nuclear fuel materials received from reprocessed fissile & fertile materials for sustenance of three stage nuclear power programme.

In India, various organizations under the umbrella of Department of Atomic Energy (DAE) are carrying out different activities involved in nuclear fuel cycle for successful implementation of nuclear power programme. Exploration of uranium resources is carried out by Atomic Minerals Directorate for Exploration and Research (AMD); mining, milling and processing of uranium for production of yellow cake is carried out by Uranium Corporation of India Limited (UCIL); fabrication of UO_2 pellets from yellow cake followed by manufacture of fuel assemblies and reactor core components are under one roof of Nuclear Fuel Complex (NFC). Electricity generation using nuclear fuel assemblies in nuclear reactors is the responsibility of Nuclear Power Corporation of India Limited (NPCIL) and reprocessing of spent nuclear fuel and nuclear waste management are carried out at Indira Gandhi Center for Atomic Research (IGCAR) & Bhabha Atomic Research Centre (BARC).

5 "Radiation"

Radiation is omnipresent in the form of naturally existing (i) cosmic radiation (ii) terrestrial radiation (iii) internal radiation and to a very insignificant extent due to manmade activities. Radiation is the emission of energy in the form of particle or electromagnetic waves. Few examples of types of radiation in day to day life are ultraviolet, visible light, x-rays, emissions from naturally occurring radioactive materials (uranium, thorium & potassium), sound waves, microwaves from an oven, radiation from cell phone and Wi-Fi router, radio waves, a laser beam, etc.

Spontaneous emission of electromagnetic energy from the nucleus of an atom is known as radioactivity. Man has been utilizing various forms of radiation for the welfare activities in science, research, industry, environmental protection, medicine and academic fields.

Due to lack of awareness and improper understanding on the benefits of radiation, some sections of the society have apprehensions on the advantages of radiation, more specifically radiation from the nuclear sources. These apprehensions are being addressed to create awareness based on facts.

Radiation and Nature

Is an environment without radiation possible? Absolutely No! Because radiation and radioactive materials are integral part of our environment (Fig.6). Certain radiation is always present on the Earth and we are invariably exposed to radiation every day, which is known as Background radiation.

- We are continuously exposed to cosmic radiation from space.
- Radioactive substances are present in the earth, in the construction materials of the dwellings and in the food, we eat and drink.
- The air we breathe invariably contains radioactive radon which is present in the atmosphere.
- Radioactive polonium and radium are present in our bones.

- Our muscles contain radioactive carbon-14 and potassium-40.
- We also receive exposure, especially for medical reasons from man-made radiation, such as X-rays, radiation used to diagnose diseases and for cancer therapy.

The background radiation is not uniform everywhere on earth. Some parts of the earth receive high background radiation and some relatively less. The intensity of background radiation depends on where we live, the composition of ground, building materials, season, latitude and weather conditions. The global average natural background radiation is 2.4 mSv/yr.

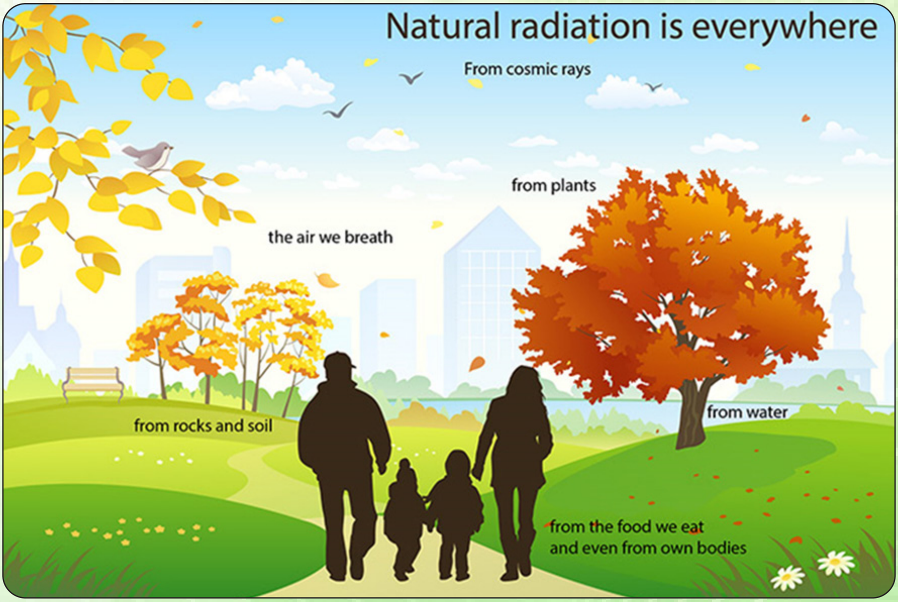


Fig.-6: Radiation and nature
(Source: Canadian Nuclear Safety Commission website)

Sources of Radiation

The sources of radiation can be natural, which exists everywhere in the environment as background radiation (both external and internal) or it can be from man-made. The natural sources of radiation includes extra-terrestrial sources like outer space from where we receive cosmic rays; terrestrial sources such as rocks, soil and air having radioactive elements; and living beings, as all of us have some amount of radioactive elements like polonium, radium, potassium-40 and carbon-14 in our bodies which are a cause of internal radiation.

Besides, there are several man-made radioactive sources to which knowingly or unknowingly public is commonly exposed in their daily routines (Fig.7). They are

- Medical sources (by far, the most significant man-made source)
  - Diagnostic x-rays
  - Nuclear medicine procedures (iodine-131, cesium-137 and others)
- Consumer products (cell phones)
- Building and road construction materials
- X-ray security systems
- Fluorescent lamp starters
- Smoke detectors (Americium)
- Luminous watches (Radium)
- Lantern mantles (Thorium)
- Tobacco (Polonium-210)
- Optical glass
- Few types of ceramics

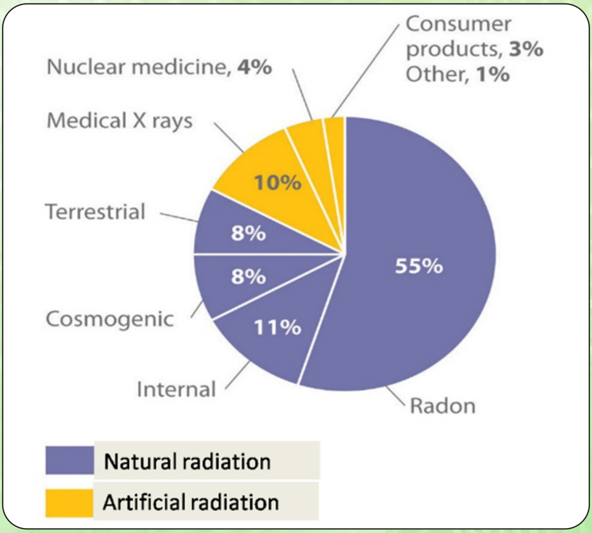


Fig 7: Radiation from different sources
(Source: Office of Civilian Radioactive Waste Management in https://chem.libretexts.org/)

On average, radiation exposure due to all-natural sources amounts to about 2.4 mSv a year and can vary, depending on the geographical location.

What is the reason for these natural and man-made sources emanating radiation? The reason is that they contain certain elements which are naturally radioactive.

Every radioactive element decays by emitting one or more of the three kinds of radiation: alpha, beta and gamma, which have different energy levels. Accordingly, these differ in the distance to which they can pass through matter. Alpha particles have a range of the order of centimeters in air, i.e., over this distance they slow down and stop. Beta particles have higher range than alpha particles and accordingly penetrate more. Gamma rays have ranges several times greater than beta particles (Fig.8).

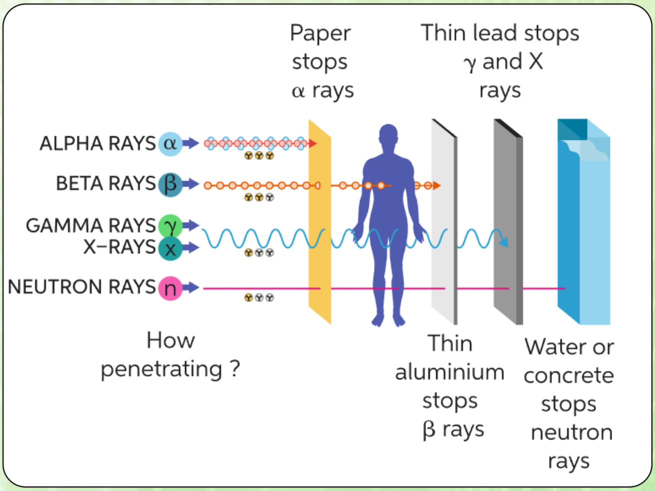


Fig 8: Penetrating power of different types of radiation (Source: https://www.chegg.com/learn/physics)

Radiation in environment around the World and in India

As already explained, man has always been living in the presence of radiation, whether it is external or internal. Some of these exposures are relatively constant and uniform throughout the world. Some coastal parts of Kerala and Tamil Nadu have high background radiation because of the presence of monazite concentration in the sands. The effect of exposure on human body is generally expressed in terms of dose. For x-rays, gamma rays and beta radiation, the conversion factor between absorbed dose in µGy and equivalent dose in µSv is one (1). So, we can say µGy equals µSv.

State weighted average terrestrial radiation levels (µGy/yr) in different states of India is given in figure-9. It is not always that U+Th are the major contributors to environmental radiation; K is found to be a major source of radiation in several rocks in the earth's crust. The weighted average of terrestrial radiation for the different states correlate closely with the dominant type of rock formation covering the respective state.

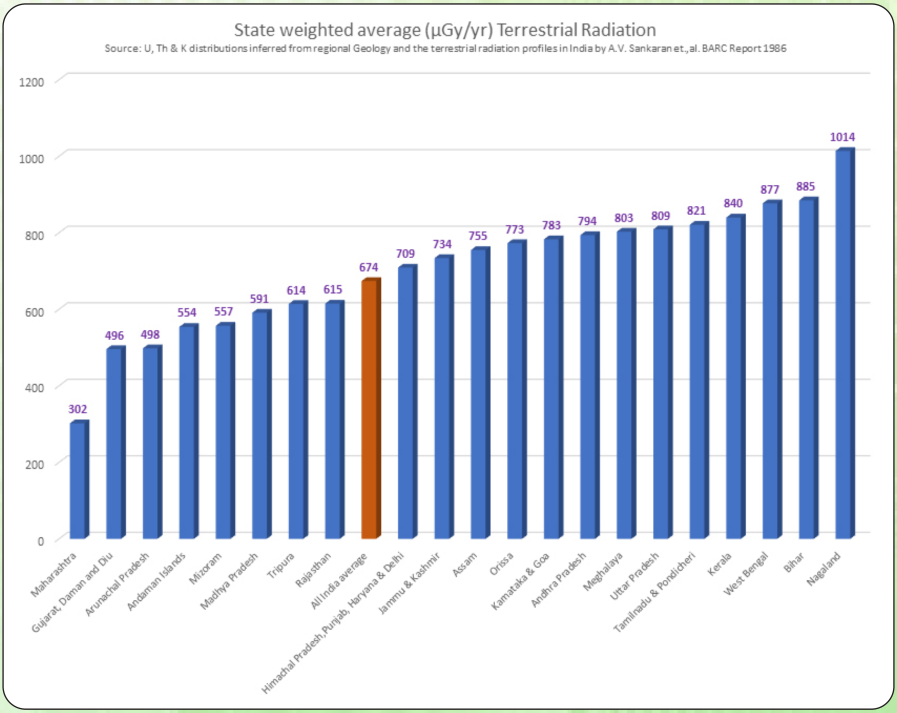


Fig 9: State weighted average of Terrestrial Radiation of different states

Around the world, there are some areas with high background radiation is given in Table-3. Gaurapari beach in Brazil has highest terrestrial background on Earth. A week's vacation here is equivalent to staying for three years near Chernobyl. Still, people visit this beach and take sunbath in the beaches and there are no reported health issues. Studies revealed that the cumulative High Background Radiation (HBR) dose was not related to the mortality due to cancer in any of the HBR areas around the world. Similarly, in coastal HBR areas in India, people are living without any major health issues and studies showed that no excess cancer risk, birth defects or genetic disorders from exposure to terrestrial gamma radiation.

Table-3: Areas with high background radiation around the world

Country	Area	Dose*	Remarks
Brazil	Guarapari	24.5	Monazite sand
China	Yangjiang	3.2	Monazite particles
India	Kerala	15.7	Monazite sand
Iran	Ramsar	7 - 3.5	Spring water
Italy	Orvieto town	4.9	Volcanic soil

* Average values are given, except for Iran.
• UNSCEAR, 2000

Radiation in rocks and minerals

In nature, all rocks exhibit natural radioactivity at different levels that is due to the decay of radionuclides that are typically present in minute quantities (measured in parts per million). The natural radiation levels of soil and rock depend on the presence of radioactive elements (i.e. uranium, thorium and potassium). Radioactivity in minerals is caused by the inclusion of naturally-occurring radioactive elements in the mineral's composition. Radionuclides within rock and sediment may contribute to the radioactivity in groundwater.

Radiation and Health

The biological effects of ionizing radiation arise from its interaction with the cellular matter of a living tissue. The effect depends on the type of radiation and the absorbed dose. For a given dose, the effects are the same, whether it is from a radiation source outside the body or from materials within.

Permissible annual dose for those exposed to radiation at work in India is 20 mSv. For members of the public, the limit is 1 mSv above background, though many receive a negligible fraction of that dose in a year.

For example, one chest X-ray will give about 0.2 mSv of radiation dose and a CT scan gives about 1-10mSv depending on the organ. The average dose to a person from background radiation in nature is 1 to 2 mSv per year. Radon gas in homes on average causes additional doses of about 1 to 3 mSv per year.

There are a few high natural background radiation areas along the coastal tracts of Kerala and Tamil Nadu in India and around the world, where the annual radiation dose received by members of the general public is several times higher than the International Commission on Radiological Protection (ICRP) dose limit for radiation workers. Still there is no evidence so far of any increase in health effects epidemiologically. Many scientific studies in Kerala on people living permanently, where the radiation levels are high did not show excess cancers, birth defects or Infertility attributed to radiation.

The radioactivity content in the environmental matrices and the radiation exposure to the public due to the operation of nuclear power plant is monitored by Environmental Survey Laboratories situated at each plant. Radiation dose to members of the public near the operating plants is estimated based on gaseous release and measurements of radionuclide concentration in items of diet i.e. vegetables, cereals, milk, meat, fish etc. and through intake of air and water. It is seen that the effective dose to public around all NPP sites is far less than annual limit of 1 mSv (1000 micro Sievert) prescribed by AERB.

Radiation Technologies and Applications

The use of radiation and nuclear

techniques in medicine, industry, agriculture, energy and other scientific and technological fields have brought tremendous benefits to society. The benefits in medicine for diagnosis and treatment in terms of human lives saved are enormous. Radiation is a key tool in the treatment of certain kinds of cancer. A good percentage of patients hospitalized benefit from some form of radiation. The beneficial impacts in other fields are similar. India is a large producer of radioisotopes for the applications in the areas of health, agriculture, industry and research and make these technologies available for the benefit of common man.

Myths of a section of Society & Facts about Radiation

Although the whole world is aware of the benefits of radiation, but the panic created due to use of nuclear weapons on Hiroshima and Nagasaki and the accidents that occurred at Three Mile Island, Chernobyl and Fukushima were so deep in the mind of common man that we are still struggling to come out of it. It is important to clear the doubts and mitigate the myths.

1. Atomic Energy spreads nuclear weapons. (Memories of Hiroshima – Nagasaki).

   Fact: Hiroshima and Nagasaki bombing happened on 6th & 9th August 1945 respectively. By that time there were no nuclear reactors working. World's first nuclear power reactor came in 1954 at Obninsk near Moscow. The first five countries to build atomic bombs did so before moving to electricity generation through nuclear power. Thus, nuclear power reactors were and are not necessarily intermediate steps for making nuclear bomb.

2. Nuclear power is not safe and not good for environment. (Memories of - Three Mile Island (1979), Chernobyl (1986) and Fukushima (2011)).

   Facts:

   ➙ In Three Mile Island, public health was not at all endangered. The only outside effect was an inconsequential release of radiation, which was negligible, when compared to natural radiation in the atmosphere. This reactor was constructed based on initial designs which had some deficiencies and the accident happened due to some human errors. The next generation reactors factored these parameters and no such accident occurred thereafter for this type of reactors.

➙ The Chernobyl accident happened due to flawed reactor design operated by inadequately trained personnel.

➙ The successive generation reactors have incorporated multiple layers of safety mechanisms minimising the risk of accidents.

➙ The safety process in India is very rigorous from site selection, to design, manufacturing, operation and monitoring. Such possibility does not arise in Indian reactors due to inherent safety features incorporated in the design and incorporation of multiple barriers of safety like the double containment structure to contain all the radioactive nuclides.

➙ Fukushima accident occurred due to flooding of reactor as a result of tsunami, whose intensity is beyond the design parameters of the site.

Such possibility does not arise in Indian reactors due to several safety designs.

The global nuclear industry with about 440 operating reactors is having about 18,000 reactor years of operational time and has produced just one serious accident with not a very large number of casualties immediately or even many years after the accident. Meanwhile, production and consumption of fossil fuels yields a constant flow of accidents and diseases, in addition to emission of the greenhouse gases. As per a WHO report, about three million people die each year due to air pollution from the global energy system dominated by fossil fuels.

In India, utmost priority for safety is accorded in all the nuclear facilities and they are sited, designed, constructed, commissioned and operated in accordance with strict quality and safety standards. The regulatory framework in the country is robust, with the independent Atomic Energy Regulatory Board (AERB) having powers to frame the policies, laying down safety standards, monitoring and enforcing all the safety provisions. The AERB exercises the regulatory control through a stage-wise system of licensing. As a result, India's safety record has been excellent.

3. Presently only India is pursuing nuclear power while others like Germany, Austria, Norway, etc. are giving it up.

Fact: Mis-information and false statement. Currently, around 55 nuclear power reactors are under construction in different countries, including China, Russia, Korea, Japan, France & Finland by 2030.

Thirteen countries in 2020 produced at least one-quarter of their electricity from nuclear. France gets around three-quarters of its electricity from nuclear energy, Slovakia and Ukraine get more than half from nuclear, whilst Hungary, Belgium, Slovenia, Bulgaria, Finland and Czech Republic get one-third or more. South Korea normally gets more than 30% of its electricity from nuclear, while in USA, UK, Spain, Romania and Russia about one-fifth of electricity is from nuclear. Earlier, Japan used to rely on nuclear power for more than one-quarter of its electricity and is expected to return to somewhere near that level in near future.

Globally, nuclear power capacity is projected to rise in the New Policies Scenario from 393 GW in 2020 to 792 GW in 2050 and nuclear energy could contribute about 12% of global electricity by 2050. Almost all reports on future energy supply from major organizations suggest an increasing role for nuclear power as an environmentally benign way of producing reliable electricity on a large scale.

4. Highly radioactive nuclear waste is a problem without solution. Future generations will suffer because of it.

   Fact: Many a times it is commented that nuclear waste is an insoluble problem-a permanent and accumulating environmental hazard. The reality is that of all the energy forms capable of meeting the world's expanding energy needs, nuclear power yields the least and most easily managed waste. On the contrary, it is the fossil fuel and not nuclear power that presents an insoluble waste problem.

This has two aspects -

- The huge volume of waste products primarily gases and particulate matter.
- Method of disposal, which is dispersion into atmosphere.

A 1000 MWe coal fired power plant generates about 6.5 million tonnes of carbon dioxide, 9,000 tonnes of sulphur dioxide, 4,500 tonnes of NO_x, 6,25,000 tonnes of ash and 400 tonnes of toxic heavy metals in a year. Whereas, a 1000 MWe Nuclear power plant generates 35 tonnes of high-level waste, 310 tonnes of intermediate level and 460 tonnes of low level waste per year. Nuclear reactors do not produce any carbon dioxide, sulphur dioxide, nitric oxide and ash.

All other waste products are handled, processed and stored strictly as per AERB guidelines. AERB monitors these processes and facilities regularly and suggests corrective measures wherever necessary.

5. Most of the people in the villages near Jaduguda are suffering from various ailments like severe skin diseases, cancer, bone diseases, brain trouble, kidney diseases, hypertension, central nervous system disorders, insomnia, fatigue, joint pains, genetic disorders, etc.

Fact: Twenty-six specialists including physicians, scientists and academic staff, many of them from non DAE establishments, carried out three separate health surveys around Jaduguda, Jharkhand. They did not find any case of defective foetus development and mental retardation in the children. Cancer cases due to radiation exposure were also not found. They found that the villagers were suffering from conventional health problems, which could be seen in any village with similar socio-economic conditions.

The team concluded that the above disease pattern cannot be ascribed to radiation exposure. They concluded that the alleged health effects are not caused due to radiation.

6. Radiation from nuclear reactors causing cancer to the workers and people in the neighborhood and genetic disorders in their future generations.

Fact: This is misinformation and not based on facts. The environmental matrices and the exposure to the public is constantly monitored by the laboratories at power plants. Similarly, the exposure (both external and internal) of the occupational workers is monitored regularly and the data has shown that all the workers are receiving dose well within permissible limits, prescribed by AERB.

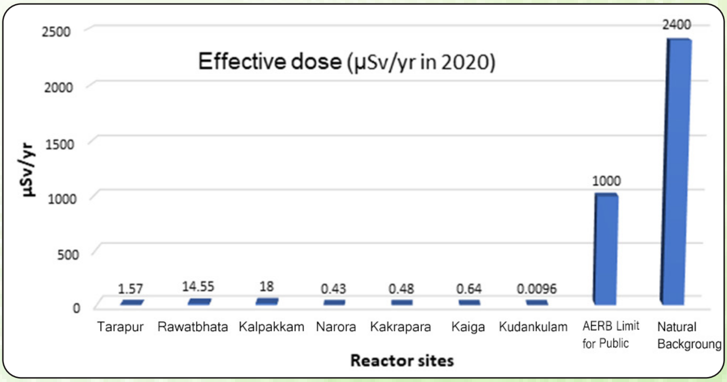


Fig 10: The radiation levels around different Nuclear Power Plants in India (Source: AERB Annual Report 2020)

The radiation levels around the Nuclear Power Plants (NPPs) are an insignificant fraction of the existing natural background, as shown in the figure-10 (AERB limit 1000 micro Sievert). Independent Epidemiological surveys of occupational workers and families at NPP sites, carried out by Tata Memorial Centre, have shown no statistical difference in incidents of cancer. 40 years of commercial nuclear power in India and more than 50 years internationally have not indicated any increase in cancer occurrence in population around NPPs. Annual dose for those exposed to radiation at work at present in India is 20 mSv. For members of the public the limit is 1 mSv, though many receive a fraction of that dose in a year.

It is to point out that toxic chemicals released from chemical and petrochemical industries, coal fuelled power stations and burning of fire wood and cow dung can also cause cancer and genetic disorders.

7. Strontium-90 and tritium

are two beta-emitting radionuclides routinely released from nuclear power reactors during normal operation. Xenon-135 is released regularly by nuclear reactors.

Fact: The radioactivity content in the environmental matrices is assessed using sophisticated radio-chemical analysis and highly sensitive instruments by Environmental Surveillance Laboratories, situated at each NPP. The dose resulting from NPP operation is about 1-2% of the authorized dose limit and is a small fraction of the natural background radiation. The doses at further distances are still lower.

Conclusion

Radiation and radioactive materials are part of our environment. Radioactive materials are present around us and within our body also. Everyone is exposed to background radiation daily. Radiation sources are both natural and man-made. There are some places around the world with high background radiation. But, people visit those places regularly and there are no health issues reported due to radiation from these areas. The use of radiation and nuclear techniques in medicine, industry, agriculture, energy and other technological fields has brought tremendous benefits to the society. Although, the benefits are known, there are doubts and fears in the mind of a section of society about nuclear energy and radiation.

The impact of nuclear accidents has been a topic of debate since the first nuclear reactors were constructed in 1954 and has been a key factor in public concern about nuclear facilities. Abundant technical measures to reduce the risk of accidents or to minimize the amount of radioactivity released to the environment have been adopted. In the long history of nuclear power generation there are only three nuclear power plant accidents, which are the Fukushima Daiichi nuclear disaster (2011), the Chernobyl disaster (1986) and the Three Mile Island accident (1979).

In India, safety is accorded top most priority in all the nuclear facilities, starting from selection of the site, design, construction, commissioning and operation of the installation. Due to this, India's safety record has been excellent.

6 "MINERAL EXPLORATION AND MINING FOR URANIUM"

Mineral Exploration

Mineral Exploration is the term used to describe a wide range of activities aimed at searching and delineating the extent of a mineral deposit. Mineral exploration is as old as human civilization. The paleolithic man looked for sharp stones for hunting and in later periods several techniques were utilized for discovering and recovering different minerals. It is the process of searching for evidence of any mineralisation hosted in the surrounding rocks. Since ancient times, many metals like iron, copper, lead, zinc, mercury, gold and silver have been known to man-kind. As these metals occur mostly in the form of ore and have to be extracted from the ores, it is natural to assume that since the very early days of civilisation, man has been aware of the existence of ore concentrations (mineral deposits) in certain places. Metallurgy is an offshoot of mineral exploration and development of modern industry owes its existence to mineral discoveries, their evaluation, mining and processing.

Today the mineral products of the earth are so commonly used that they affect every aspect of our lives. Mineral resources are essential to our modern industrial society and they are used everywhere. For example, the glass we use for drinking coffee/tea (made from melted quartz sand), the ceramic plate we use for eating (created from clay minerals heated at high temperatures), salt that we sprinkle on our food (halite), the steel utensils we use (from iron ore and other minerals) in our kitchens, the magazine we read (coated with up to 50% kaolinite clay to give the glossy look), and the cellphones we use for communication (containing different metals including copper, silver, gold, platinum and REE) are all made from minerals. We need minerals to make fertilizer, tractors, houses, concrete roads, cars, electrical transmission lines, appliances, computers, and jewellery. Without mineral resources, industry would collapse and living standards would tumble. Adequate supplies of minerals are essential for the maintenance/growth of our economy. Reliable and reasonably priced supplies are essential to the smooth functioning of the economy and to our national security in a world, which is subject to frequent political and military conflicts. A significant portion of our national economic activity and employment, particularly in certain regions, is based on the mineral-producing sectors of the economy.

Considering all of the above, as well as the increasing difficulties of exploring for and producing minerals in foreign countries, it is clearly in the national interest to consider carefully opportunities for the discovery, development, and production of domestic mineral resources.

Mineral exploration aims to discover deposits of minerals and rocks that can be used to meet the resource needs of society. It encompasses the search for industrial raw materials (e.g., clay, limestone, sulphur, salts, and fertilizer minerals and rocks), ores from which metals are extracted (e.g., iron, copper and zinc ores), and gemstones (diamonds, sapphires and opals), and includes the search for fuels (coal, oil & gas and uranium).

Many people are not aware about where do these minerals occur and how are they identified. Mineral deposits do not occur everywhere. They occur in the earth at specific locations depending on the type of geological terrain and the type of mineralising events that take place in that particular terrain. They are the result of uncommon events (mineralising) which have operated in the earth at a specific geological time in the past. So, mineral deposits are discovered where they are existing and no one has control over its occurrence/ location. Ore deposits form when minerals are concentrated in rocks, sometimes by a factor of many thousands.

Mineral deposits are found by prospecting. Prospecting activities usually begin with the study of all available geological information, existing mineral deposits and their host rocks and their mode of occurrence in an area to determine whether the area is favourable to certain types of mineralisation and ore deposition. Different types of rocks concentrate different metals, so that if an exploration agency is looking for gold, it looks for rock types that are favourable to gold deposits. If the agencies interest is in industrial minerals, such as calcite, apatite, coal, etc., it looks for other rock types. Considering all the relevant information, scientists / geologists work to find clues as to where there are important metals such as copper, gold and nickel and minerals such as apatite (needed in fertiliser) in large quantities. Deposits are hard to find, and prospecting takes a long time.

Majority of mineral exploration activities of the country are carried out by the Geological Survey of India (GSI) under Ministry of Mines, which is a 150 year old Government Institution. In respect of atomic minerals, such activities are carried out by Atomic Minerals Directorate for Exploration and Research (AMD) of the Department of Atomic Energy. These organisations carry out the activities as per the statutory provisions contained in the two Acts of Parliament, viz. Mines and Minerals Development and Regulation Act, 1957 and the Atomic Energy Act, 1962. The robust growth of mineral industry and the related industrial growth is on account of the painstaking efforts of these two institutions over decades.

The start of the process comes from the generation of ideas, which are based on the geology of a region, the envisaged exploration models to broadly scan the area for potential resources that might suit a commodity of interest. Initially, large areas are selected based on the envisaged exploration model. In simple terms, mineral exploration has various stages, reconnaissance survey, detailed survey and mapping, drilling and resource estimation. Various geophysical and geochemical exploration techniques further aid in target identification. These steps are common to exploration for all minerals including atomic minerals. Any obstacles to timely mineral exploration will have a cascading effect on downstream industries and resultant slackening of industrial growth.

The exploration activities are taken up in different phases with specific objectives. In each phase, the process of selection and delineation is carried out. Areas with little or no potential are discarded. The areas remaining at the end of each phase becomes target for the succeeding phase.

During the starting phases, geological mapping, airborne / heliborne geophysical surveys, ground geological, geophysical and geochemical surveys are taken up to cover larger areas to increase knowledge base and generate potential mineral targets for advanced phases of exploration. Geo-scientists visit locations to look at the rocks and take measurements to assess whether the area may have potential for minerals. Major part of the area is rejected and further exploration will be confined to the target delineated from previous phase of exploration. Relatively close spaced surveys are carried out in subsequent phases until the target is defined for detailed exploration. During all these phases of exploration, rock chip, soil and water (ground and surface) samples are collected for studies in laboratories, besides the geological mapping at different scales. Many ore minerals are heavy, magnetic or electrically conductive, and their presence in the bedrock shows in geo¬physical measurements. One can often see high/elevated metal content in surrounding soil/ ground and groundwater due to dispersion of metals/chemical species from the ore. Scientific research and studies will be taken up to understand the rocks, their formation, composition and presence of anomalous minerals and metals of search. These studies will help in identifying the targets for detailed exploration.

The detailed phases of exploration is aimed at verification of targets/ anomalies by pitting, trenching etc. Once a target is identified, it will be explored by drilling boreholes. The boreholes enable in precise location and sampling of the target (ore) zone. Further, subsurface rock samples are obtained along the borehole path for scientific studies. Once a borehole is drilled, logging by various techniques, as per requirement is carried out to study the variation in the subsurface geophysical parameters. The geophysical logging methods includes mechanical (caliper, sonic), electrical (resistivity, conductivity), magnetic (magnetic susceptibility), radiometric (gamma-ray, neutron porosity) measurements for various purposes, which gives additional information on the subsurface, apart from geological studies on the core samples.

Also, the boreholes are drilled wide apart initially, and the spacing between the boreholes is reduced in subsequent stages to delineate the ore body of interest, if favourable results are obtained in each following stage. Finally, the mineral resources are evaluated based on the results gathered from drilling boreholes and the data generated from various scientific studies.

Uranium

In what way exploration for uranium differs from the exploration activities carried out for other minerals/ metallic ores. It may be surprising to many to know that for uranium also the sequence of exploration and the techniques remains same. The area for search may also be sometimes same. Uranium is a special element which possess an additional characteristic of emitting natural radiation. Being a naturally radioactive element, uranium emits alpha-, beta- and gamma-radiation. This special property differentiates uranium and other radioactive elements like thorium, niobium-tantalum, etc. from other non-radioactive elements and facilitates the search for their identification. Radiation survey meters are used to find the presence of uranium or other radioactive elements in rocks. But, these radiation surveys are also restricted as alpha- and beta-particles cannot travel for distances in air and even gamma-rays cannot be detected, if the mineral/ore is covered by soil. So, like other minerals, uranium or other atomic minerals exploration relies on basic mineral exploration techniques involving sampling and analysis of rocks, water and soil.

Exploration is done in many steps, and it often takes several years or even decades to find and define an ore body that can be potentially mined. Many projects may get discontinued after various stages of exploration. It is important to note that all exploration projects does not result in establishing mineral deposits and only few exploration projects lead to opening of a mine. If the exploration process identifies that minerals can be commercially extracted, then mining in the future may be possible.

Does Mineral Exploration affect Environment?

When it comes to mineral

exploration, some organisations or even common people express concerns about environmental degradation. Do these activities really cause any environmental concerns? If one looks at the work flow of all exploration activities, knowingly or unknowingly every person carries out similar activities at their level, be it for a different purpose. The geoscientists collect samples of soil, water and rocks during surveys. Sometimes they dig small pits or trenches to see whether the rock of interest is present below the soil, if present, to check how it is occurring and for collection of samples. If positive indications are obtained from testing these samples /initial stages of sampling / exploration, the presence of mineral / host rock at depth is confirmed by collecting rock samples from deeper levels through drilling boreholes. The techniques of drilling and collection of rock / core samples remains same for all sorts of minerals including uranium. In fact, it is not much different from the boreholes (borewells) drilled for groundwater. The only difference is, in boreholes drilled for groundwater, the rocks are broken into chips and fine powder whereas in boreholes drilled for minerals, mostly the solid rock samples called 'core samples' are retrieved for further studies in the laboratories. The diameter of the boreholes and drilled depth may also vary depending on the depth of occurrence of rock formation of interest. For carefully collecting solid rock (core) samples and for aiding subsequent scientific studies the boreholes drilled for mineral exploration may take more time. The final outcome will be same as in both the cases a hole is made into the ground, which can either be used for drawing groundwater or geophysical logging and evaluation of rock beneath during mineral exploration.

It is the lack of understanding that certain groups of people allege that the soil and water gets contaminated from exploration. The rocks are composed of minerals. Ore deposits form when minerals are concentrated. sometimes by a factor of many thousands in rock, through some geological process. The surrounding rocks hosting the ore deposits with high concentration of minerals/elements will naturally show elevated concentration of elements. Similarly, the soil above and the groundwater interacting with the host rocks and the ore deposit also show elevated concentration of elements in comparison with the other parts of the area. This forms the basis for scientists for collecting soil, rock, water samples in the search for ore deposits be it uranium or any other element. So, it is to understand that the exploration activities are temporary and does not result in elevated concentrations of elements in the soil, rock or water although some anthropogenic activities resulting in elevated concentration of elements viz. use of fertilizers, manures and pesticides during agriculture; animal husbandry activities; aquaculture; industrial effluents; fly ash from thermal power plants, etc. have been reported.

Atomic minerals Directorate for Exploration and Research has been involved in uranium exploration across the country. The scientists of the Directorate are systematically carrying out ground (geological, geochemical, geophysical including radiometric) and heliborne geophysical surveys followed by drilling over favourable geological domains for over seven decades. It has been time tested that the exploration activities including drilling do not cause any environmental degradation. Even after the drilling operations are concluded, the small part of the land is reclaimed back to normal. As time passes on, it will be even difficult to identify the drill hole location. Like that, in the State of Telangana, AMD has carried out exploration and successfully established uranium deposits in areas viz. Chitrial, Lambapur, Peddagattu, etc. which contribute significantly to the uranium resources of the country. All the areas of exploration are reclaimed to normalcy immediately after the closure of drilling operations. It is now difficult to mark out the area of exploration (Fig.11&12). The drilling does not disturb the soil and the fauna & flora is also not affected.

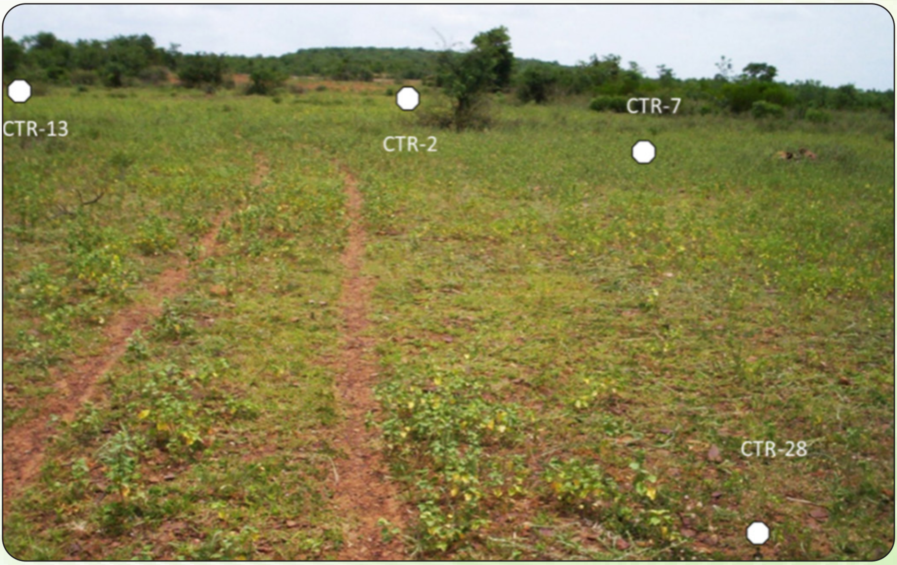


Fig.11: Drilling block in Chitrial, Nalgonda district, Telangana showing the locations of boreholes drilled earlier.

Fig. 12: The Forest Land after drilling in Chitrial Western block.

Considering all these aspects, the general public must realise that the impact of exploration activities on the public or environment, fauna and flora is negligible and the mineral supplies are important in the sustainable development of the country. The area of search and the mineral exploration techniques remains same for all the minerals, including uranium. The allegations by certain groups of society on exploration, especially uranium are baseless and must be kept at bay.

Mining

Once the dimensions of an ore body are delineated by exploration and feasibility and economic viability are established, the mineral deposit is exploited through a process called mining. Mining for the purpose of precious stones, gems and metal has been done since pre-historic times. Ancient Mining was limited where excavation is restricted up to a shallow depth (say less than 100m) for extraction of valuable minerals. Present day mining is carried out over a greater extent (more than 1000m) for extraction of valuable minerals, which are important for different applications with more scientific planning and safety precautions.

Mining is generally done by either open cast or underground methods. In case of uranium, a more technologically advanced method namely Insitu Leaching Method (ISL) is adopted for both mining and extraction. The location and shape of the ore deposit, distance from the surface, strength of the rock, ore grade, mining costs, and current market price of the commodity are some of the determining factors for selecting a mining method.

Low grade ores found closer to the surface may be profitably mined using surface mining methods, which generally cost less than underground mining methods. Many industrial minerals (limestone, clays, building stone, placer minerals including BSM) are also extracted by surface mining methods. Underground mining is selected when ore is too deep for surface mining or economically not feasible to extract ore through surface mining operations.

Underground mining involve a network of workings such as shaft, adit, decline, incline, raise, drives, etc. to access and extract the ore. Besides, providing access to the ore deposit, the underground mine development also includes permitting entry of the miners, equipment and for supplying power, water and air, as well as outlet for the mineral being mined and the waste produced. In contrast to the surface mine development where removal of significant amount of overburden is involved, the underground mining requires limited excavation and relatively small openings.

Whatever may be the method of mining, in general the mining process involves, extraction of material from the ground and subsequently the ore minerals are liberated, separated, and concentrated. The nature of these steps differs depending on composition, hardness and texture of the rock, geometry and location of ore, local environment and other considerations.

The mine produce is a combination of ore minerals containing valuable metals, other associated minerals called Gangue minerals and surrounding rock material. The gangue minerals are also considered as waste. So, the ore minerals are separated from the associated gangue minerals and waste rock material through processing at various stages. Processing of any metallic ore (e.g., gold, silver, iron, copper, zinc, nickel, lead and uranium) can involve numerous steps including crushing, grinding with water, physically separating the ore minerals from non-ore minerals, and chemically separating the metal from the ore minerals using methods such as smelting (heating the ore minerals with different chemicals to extract the metal) and leaching (using chemicals to dissolve the metal from a large volume of crushed rock). The product can be a concentrate with one or more valuable minerals, the product can also be metal plates from electro winning or metal from a smelter. The processing of uranium ore is no different from other metallic minerals and similar methodology is adopted during processing depending on the nature of ore. The resultant waste generated after processing of the ore is called tailings. Many of the non-metallic minerals and rocks do not require chemical separation techniques.

Finally, when the mining operations cease, for instance, as the ore is diminished, the mine goes through a period of mine closure. It is the final stage in the operation of most mines. Mine closure means that the mine is decommissioned and remediated. Remediation of the mine is done to provide long-term physical, chemical, and biological stability of the site to minimize potential environmental and health risks. Closing and rehabilitating the mine involves returning the mine site to an ecological state and function similar to before mining or to an ecological function and land use beneficial to nature and people in some other way.

In all these mining processes, the miners are prone to face health hazards arising out of onsite pollution due to dust, gases, noise and polluted water. The present day mines are planned addressing the miner's safety aspects. Noise in the mines is reduced by quieting the machinery and insulating the chutes by sound absorbing materials. Hearing protectors combined with regular audiometric testing is often carried out to preserve miners' hearing.

Contaminants inside the mine can occur naturally (e.g. strata gases, such as methane in coal beds or radon gas from granitic rocks or radioactive ores) or are introduced by mining activity (e.g. diesel or blasting fumes, smoke from fires, all dusts). Even human breathing liberates a contaminant (carbon dioxide) while consuming oxygen, admittedly in small amounts. Ventilation in mines is planned with a broad objective to provide a comfortable, safe atmospheric environment for the workers. It largely maintains the quality and quantity of the atmospheric environment including the quantity control of air, its movement and its distribution. Other processes specifically help to accomplish quality control (e.g. gas and dust control) or temperature-humidity control (e.g. air cooling and dehumidification, heating).

In present day mining, ventilation systems designed and operated to maintain efficient operations with a high standard of occupational health and safety to be achieved.

In addition to the above, radiological safety is believed to be a major concern when it comes to uranium mining due to emission of radiation. In most cases, the ore bodies exploited for uranium production contain very low levels of thorium and this decay chain makes an insignificant contribution to occupational gamma dose rates in the great majority of uranium producing mines in India. Where thorium comprises more than 10% of an exploited uranium ore, this will result in significantly higher gamma dose rates in the mine and plant.

The cut-off grade for considering uranium exploitation in India is 0.02% uranium oxide. In general, the grade of uranium ore being exploited around the world ranges widely, from around 0.02% (200 ppm) to as high as 20% (in the Athabasca Basin, in Canada). As the uranium grade increases, the gamma component of the annual occupational dose will increase, particularly during the mining operations. In order to reduce occupational exposures from high grade ores to an acceptable level, specialized mining techniques and engineered controls are employed in high grade ore mining around the world. When compared to the majority of uranium deposits of the world, Indian uranium deposits are of very much low in grade.

Nevertheless, gamma radiation exposures can be reduced through a wide variety of administrative and engineered control methods. The key concepts for controlling occupational exposure are time, distance and shielding:

- Reducing the time spent in gamma radiation fields;
- Increasing the distance from the gamma radiation source;
- Shielding the gamma radiation source.

In the exploitation of low grade ore bodies, it is rare for there to be any unforeseen high doses arising from gamma radiation during mining or processing.

Atomic Energy Regulatory Board (AERB), Government of India is the designated authority regulating the radiological aspects associated with uranium ore mining, processing and safe disposal of solid waste. AERB regulates and monitors the safety standards for occupational radiation dose limits which are internationally accepted (by IAEA) and also notified by the Government of India. AERB adopts the principle called “ALARA” i.e. ‘As Low As Reasonably Achievable’ level of radiation dose to the persons associated with radiation facilities.

The radiological safety of the mine workers is monitored by personal gamma dosimeters. Thermo-Luminescent Dosimeters (TLD) are currently the most popular method of assessment. TLDs are small, inexpensive, robust and easy to use, and are accepted by regulatory bodies as the standard for personal gamma measurement. They have wide acceptance in the workforce and are available worldwide. Each worker wears a TLD mandatorily while at work. The TLDs are periodically monitored, if by any chance, the exposure reaches the specified annual limit for occupational workers (20mSv), the concerned worker is shifted from the mine and assigned general duties with no scope of exposure to radiation from uranium ore for the rest of the period.

Taking into consideration the exposure limits recommended by the International Commission on Radiological Protection (ICRP), the AERB has notified the limits on effective dose that an occupational worker or a general public are permitted in a calendar year duration. The radiation dose is measured in unit called milli Sieverts (mSv). The limits of effective dose notified by Government of India for Occupational Workers shall not exceed an effective dose of 20 mSv/year averaged over 5 consecutive years or an effective dose of 30 mSv in any year.

At mine level, depending on the mineral produced and number of persons employed, the mine is required to appoint Safety Officer, Medical Officer and other competent persons to ensure safe and healthy working conditions. Every person employed in mine is required to undergo initial medical examination at the time of appointment and once every 5 years thereafter. Periodically, every mine is also required to conduct survey for airborne respirable dust at workplace.

In addition, in mines for all minerals including uranium, the miner's safety and health conditions are also monitored as per the provisions of the Mines Act-1952, the Metalliferous Mines Regulations-1961 and other rules administered by the Directorate General of Mines Safety (DGMS) under the Union Ministry of Labour. DGMS has specialist officers in mining, electrical, mechanical engineering along with the medical doctors to check the occupational health diseases, if any. The mission of DGMS is to identify and reduce risk of accidents and diseases in and around the mine. The health records of individual miners are being maintained and monitored by the DGMS.

The incidence of accidents is an important indicator of the status of safety in mines and these records are maintained by DGMS. In order to ensure the mining projects are adequately monitored, the following requirements have been put in place.

- The agencies are required to report every six months on the implementation of environmental safeguards stipulated in the clearance by the MoEF
- Field visits by the Central Pollution Control Board or AERB to collect samples and data on the environmental performance of the projects
- In case of inadequate compliance, the issue is taken up with the concerned State Governments and nodal ministries.

The radioactive waste management usually remains the point of discussion. Radioactive waste from mining and milling of uranium ore occur in three forms i.e. solid, liquid and gaseous waste. All the discharges are allowed only after suitable monitoring as per the guidelines issued by AERB to check the effectiveness of the waste management control. Solid waste rock generated during mining activities may have very low uranium content and is mostly used for backfilling the mined-out stopes. Liquid waste in the form of mine water, that is not utilised in mining and milling operations is treated in the water treatment plant (WTP) and disposed-off conforming to the norms for disposal of radioactive pollutants. The gaseous and particulate matter from an underground mine is being discharged in such a manner that the public is not exposed and the pollutants are below the permissible limits.

Public also express concerns that, if the walls/dams of the impoundment breaks, then a lot of contamination can be released very quickly. Additionally, if a tailing pond dries out, the metals may be transported as dust on the wind and thus have the potential to be inhaled by nearby residents. Presently, plastic liners (HDPE sheets) or suitable impervious lining are being put down to prevent percolation of these contaminated waters into the groundwater system, and the water from tailings ponds is usually treated to neutralize the acids. Once filled, tailings ponds are covered (capped) with an impermeable liner, or soil and water flow is managed, treating any water leaving the ponds.

The Ministry of Mines (MoM), Government of India is responsible for the entire minerals and mining sector in the country that includes legislation, administration, policy formulation etc. in respect of all mines and minerals other than natural gas, petroleum, but including offshore minerals. In India, the minerals are classified as minor minerals and non-minor (i.e. major) minerals. The policy and legislation relating to minor minerals is entirely delegated to the state governments while policy and legislation relating to the major minerals is dealt by the MoM. All the mineral legislations in the country conform to the provisions of the MMDR Act, 1957. Geological Survey of India (GSI) under the MoM carries out exploration, geological mapping and mineral resource assessment in the country. Indian Bureau of Mines (IBM), under the MoM is mainly responsible for regulation of mining in the country. It carries out inspection of mines, approves mining plans and mine closure plans and conducts environmental studies to minimise environmental impact due to mining. Besides being a regulator, it also maintains a repository of information relating to minerals and mining activity in the country and all the mines are required to file mandatory returns with IBM. Mineral concessions in India are granted to Indian nationals or to a company as defined in Section 2 of the Companies Act 2013. In respect of Atomic Minerals, mining leases are granted under Atomic Minerals Concession Rules, 2016. If the grade of atomic minerals is equal to or above a specified threshold value, then mining leases are to be granted to Government companies based on the nomination by DAE. AMD, a constituent unit of DAE accords the approval for mining plans and is the authority for administration of mineral concessions, systematic development and conservation of mineral resources in respect of atomic minerals.

With respect to the mineral administration and regulation, each State Government is vested with powers on all the mineral administration related matters (such as grant of concessions, collection of royalties and payments etc.).

To sum up it is essential that the mineral resources are to be exploited where they occur in nature and for self-reliability of a nation on supply of these resources. Each mineral deposit has a unique geological conditions of deposition and concentration. For running a robust economic growth of any country, requirement of minerals and metals is a major comforting factor. India is blessed with large resources of minerals and minimal dependence on import of various minerals. Though exploitation of minerals do cause certain dislocation of habitations, in the larger interest of the nation and to have self-reliance in the mineral supply chain, it is essential that the available resources are optimally exploited for the development of the nation.

7 “ Application of Radiation Technologies for Societal Benefits ”

Nuclear energy is one of the promising green energy options, to meet the ever increasing energy demand. It is one of the low cost, negligible carbon foot print, reliable energy sources and is essential to minimise greenhouse gas emissions. In addition to nuclear power production, various radiation technologies were also developed for societal needs and some of them are discussed below to showcase the advantages of nuclear energy.

1. Healthcare

Radiation medicine helps millions of patients worldwide in diagnosing and therapy applications. In general, radiation and radioisotopes have applications in the following categories of health care;

- External radiation therapy
- Brachytherapy / Internal radiation
- Nuclear medicine
- Ruthenium-106 Plaque for treatment of Ocular Tumours
- Radiation Sterilisation of health care products
- Tele-ECG machine

1.1. External Radiation Therapy

Radiation is used for controlling or eliminating cancerous growths formed by rapidly dividing cells. The radiation source of appropriate dose is placed in a shielded housing and beam of radiation emanating from the source is directed towards the tumour for treatment. It is also called as External Beam Radiation Therapy (EBRT). It is a well-targeted therapy, in which a specific part of the body is treated. If throat is effected by cancer, radiation therapy is given to throat only. Cobalt-60 sources are being used in most of the 225 Teletherapy units set up in 62 cities in India for cancer treatment. These units treat around 20 lakh cases for various diseases, including 1.2 lakh cancer patients. Now-a-days, electron accelerators are also widely used for radiotherapy, because of its precision with which it can irradiate and destroy tumours.

Bhabhatron is one such external beam radiation therapy machine designed for the treatment of cancer patients by Bhabha Atomic Research Centre (BARC), DAE. It is a computer-controlled system using radioactive cobalt-60 isotope as the source of radiation to deliver planned amount of radiation exposure to the designated target safely and accurately.

1.2. Brachytherapy / Internal radiation

Brachytherapy is a type of radiation therapy which is used to treat cancer. It is also called as internal radiation because it involves placing of radioactive materials (sources) inside the body. It allows doctors to deliver higher doses of radiation to more-specific areas of the body, compared with the conventional form of radiation therapy (external beam radiation) that projects radiation from a machine outside of your body. Cancers of prostate, breast, lung, uterus, cervix, head and neck are treated using brachytherapy technique. The main advantage of brachytherapy is overall treatment time is shorter because of high dose rates. Iridium-192 and Cesium-137 are the main sources used in brachytherapy for cancer treatment. After treatment, the radioactive materials are removed from the body. Board of Radiation and Isotope Technology (BRIT), an industrial unit of DAE, supplies brachytherapy sources.

1.3. Nuclear medicine

Nuclear medicine is a specialized area of radiology that uses very small amounts of radioactive materials or radiopharmaceuticals to examine the function and structure of organs and tissues. It is also used for treatment of various ailments of heart, gastrointestinal, endocrine glands, neurological disorders etc. Radiopharmaceutical contain a radioactive element and a drug component and employ both nuclear properties of radionuclides and pharmacological properties of pharmaceutical for diagnosis and therapy. The treatment involves incorporation of radiopharmaceutical into natural biological processes of the body and its signal can be seen using a gamma camera (a device that detects gamma radiation). Positron Emission Tomography (PET) is one of the precise imaging technique which helps in study of organ function for deciding treatment protocols.

For example, images of the heart taken with a Single Photon Emission Computed Tomography (SPECT), which images how much blood is flowing into all parts of the heart muscle. These images help doctors to determine the severity of the heart disease, which helps in filtering the patients who don't need procedures like cardiac catheterization, coronary angiography, etc. Around 200 radioisotopes are routinely used as tracers in imaging various organs/tissues of human body.

Technetium-99m (Tc-99m) is the most commonly used radionuclide for diagnostic imaging. The other radionuclides used in SPECT are Iodine-131 (for diagnosis and treatment of thyroid disorders), Iodine-125 (for treatment of ocular tumours and prostate cancer), Phosphorus-32 (for pain relief in bone cancer cases), Samarium-153 (for treating arthritis of large and medium-size joints), Fluorine-18 (to diagnose benign and malignant diseases of the skeleton), etc. The various radiopharmaceuticals available for imaging every major organ / tissue of human body are given in figure-13. These radiopharmaceuticals and allied products are supplied by BRIT to nearly 120 nuclear medicine centres in the country.

Cancer hospitals were set up in various cities across India by Tata Memorial Centre (TMC) with benevolence of the DAE. Every year, nearly 1,20,000 new patients from all over India and neighbouring countries visit the clinics of TMC. Of these, over 70% patients were registered in the General category and whose treatment costs were additionally subsidized.

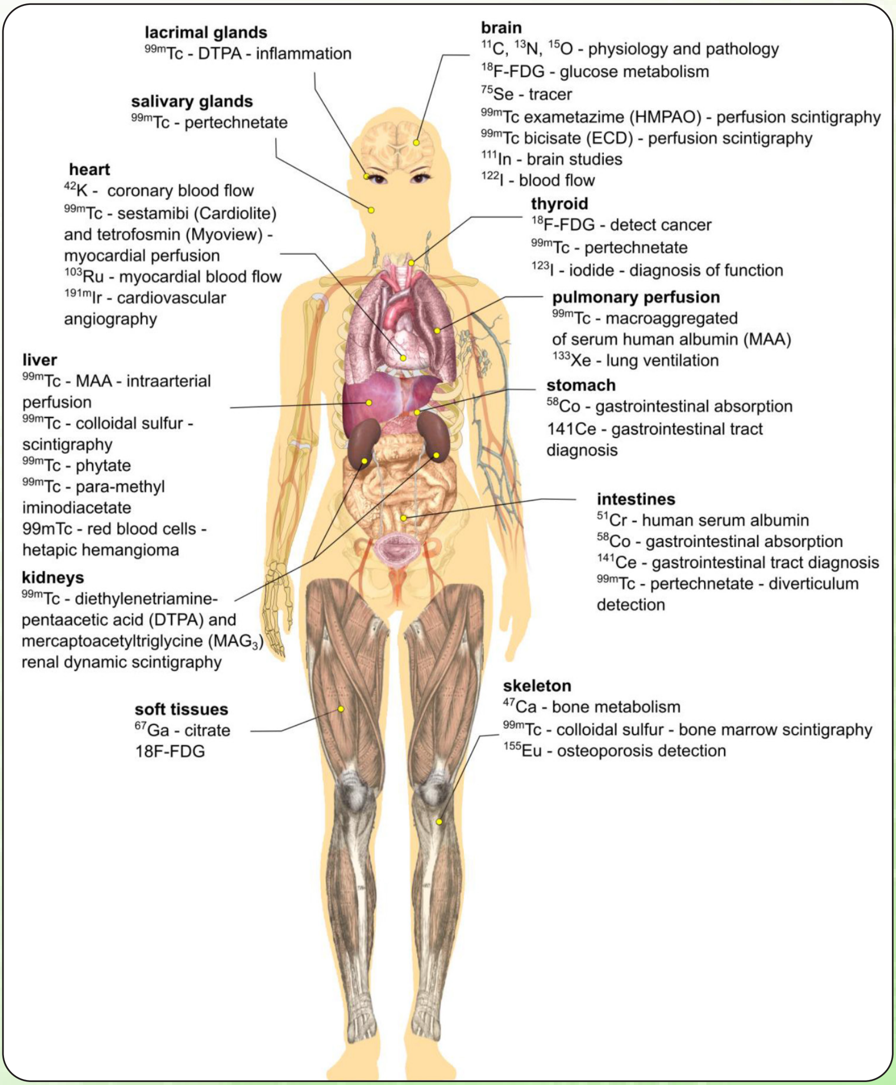


Fig-13: Various radiopharmaceuticals available for imaging every major organ / tissue of human body

(Source: Image reference: Filipe P, Massabni A& Orvig C (2019) Radiopharmaceuticals for diagnosis in nuclear medicine: A short review, Ecletica Quimica Journal, 44, 11-19)

1.4. Ruthenium-106 Plaque for treatment of Ocular Tumours

Radiation has the property of killing cancer cells, so radiation therapy can be used for treatment of tumors without collateral damage of healthy tissues. For the treatment of deep seated tumours as well as tumours of sensitive organs, radiation source in sealed condition is placed near to the location of tumour. In this direction, first indigenous Ruthenium-106 Plaque was developed for treatment of Ocular Tumours. Ruthenium is a fission by-product of the nuclear reprocessing cycle with a typical yield of ~0.4%. It is recovered as a by-product from the nuclear waste and is purified to medical-grade Ru-106 followed by manufacture of plaques. Ruthenium-106 plaque is an import substitute and helps in reducing the cost of treatment thus saving vision of a large number of patients.

Ru-106 plaques are supplied to hospitals through BRIT. DAE has collaboration with Dr. Rajendra Prasad Centre for Ophthalmic Sciences, All India Institute of Medical Sciences (AIIMS), New Delhi for using these plaques. For the first time these plaques were used for the treatment of a patient with Choroidal Hemangioma in September, 2020. Within two months, 10 patients have been treated satisfactorily using these plaques.

1.5. Radiation Sterilisation of health care products

Radiation Sterilisation is another important application of radioisotopes towards health care offered to the Indian medical industry. The ability of gamma radiation to kill micro-organisms is the basis for radiation sterilisation and is used for sterilisation of various medical products such as disposable syringes, surgical sutures, cotton dressing, drugs, PPEs and related products etc. The advantage of this over conventional techniques is that the sterilisation can be applied on medical products after final packing so that the product remains sterile up to the point of use. Moreover, it is a cold process, heat sensitive materials like plastics used in medical products are also sterilised without any adverse effect. The Irradiation Sterilisation of Medical Products

(ISOMED) Plant at Trombay was the first unit started by the Department of Atomic Energy for this purpose. Over a million radiation sterilised midwifery kits and delivery packs have been distributed in rural areas through rural health programmes, which helps in preventing infection of mothers and helping to minimize infant mortality rate.

1.6. Tele-ECG machine

Rural and remote areas of the country have poor access to well-equipped hospitals, which leads to serious consequences in case of cardiac emergencies. So, a simple Tele-ECG machine was developed to cater such emergencies in such remote locations. It is a portable, lightweight and low cost 12-channel device and is powered by a rechargeable battery which can be charged with any mobile charger. A mobile based app facilitates taking ECG and sharing it through WhatsApp. It can be handled by local health care workers with minimal training. An inbuilt interface is available for printing of ECG report.

2. Agriculture

In the field of agriculture, radiation technology is contributing to the development of high yielding crop seeds, optimizing use of fertilizers, pest control and preservation of food items. Nuclear technology is an important means in modifying the properties of seeds at genetic level which helps in increasing the crop yield. Gamma radiation only accelerates the mutations which otherwise occurs naturally over a much longer periods of time. Mutations can be in such a way that the crops mature early, increased yield, to withstand biotic and abiotic stresses like reduced water supply, increased pest resistance, and to obtain better nutritional quality. So far, BARC has released 49 seed varieties for commercial exploitation. The varieties released are for pulses, cereals (mainly rice) and oil seeds. The seed varieties released are genetically enhanced and not genetically modified i.e. gene sequence of foreign bacterium is not introduced. In addition, the farmers can preserve a part of the crop for its use again for sowing.

For example,

- Dubraj mutant variety developed in collaboration of IGKV, Raipur. The features of this variety in comparison to parent Dubraj rice are (1) height reduction by ~60%; (2) maturity time reduction by~7%; and (3) yield increase by ~46%.

- ~24000 quintals of seeds are supplied to farmers through agricultural universities at Dharwad, Akola and Bhubaneswar.

3. Food Preservation

Radiation processing of food involves treatment of food items with gamma radiation. Gamma rays destroy or inactivate organisms, thereby extend the shelf life of certain foods. Processing with low dose radiation is used for sprout inhibition in onion, potato, ginger, garlic and yam; insect disinfestations of cereals, pulses and their products as well as spices and dry fruits, and making meat and meat products pathogen free. Radiation processed products remain closer to the fresh state in flavour, colour and texture. The process does not cause loss of natural juices. The technology is effective, clean and very safe. It is the superior technology in comparison to fumigants which are currently used, as these are recommended to be phased out by international organisations because these are harmful to health and environment. At present, 3 radiation processing plants are being operated by Department of Atomic Energy and 18 radiation processing plants have been commissioned in the private and Semi Government sector.

4. Industrial applications of Radiation technology

BRIT provides radioisotope based products and services for industrial use on commercial scale. These cover products such as radio sources, radio chemicals and labelled compounds; equipment such as radiography camera, gamma chambers and others, and services such as radiation processing for sterilization of medical products. The industrial applications are spread to gauge measurement, thickness measurement of plates and pipes, leak detection; sensors in automotive equipment and other applications in industry.

Radiotracers are extensively used for locating leakages in oil and gas pipes and seepages of water from dams and water-bodies; study of sediment transport at ports and harbours, flow measurements and water resource management.

Isotope hydrology has emerged as a separate discipline and has proved to be of great value in the field of water resource management. The radioactive nuclides such as tritium and Carbon-14, which exist in the environment, are used to collect information on the source and dynamics of water bodies such as extent of chemical reactions in the subsurface, subsurface residence times, etc. BARC has been using this technology in Himalayan region for ground water recharge. The technology has been successfully demonstrated in other states viz. Andhra Pradesh, Gujarat and Karnataka. BARC has done extensive isotope hydrology related work in Uttaranchal and Himachal Pradesh. Recharge studies at 8 different regions for 85 different springs have been carried out. The study identifies the locations where bunds can be constructed for increased ground water recharge.

5. Technologies developed for waste management

The technologies developed for treatment of waste or sludge, are economical and automated during complete cycle. A few of them are detailed below.

5.1. Sludge Hygienisation Plant

A radiation based technology was developed for sludge treatment under urban waste management such as city municipal corporations. This technology uses gamma radiation from Cobalt-60 source for hygienisation of sewage sludge, which results in reduction of all pathogenic microorganisms in the sludge to a level that they cannot be multiplied further. The advantages of hygienised and enriched sludge are pathogen free manure, a rich source of organic carbon & micro nutrients, removal of total odour, possible disintegration of hazardous chemicals, safe for human handling. It is efficient organic manure for horticulture and agricultural applications. This technology was developed in collaboration with Vadodara Municipal Corporation and set up a "Sludge Hygienisation Research Irradiator (SHRI)" facility at Vadodara which hygienises the liquid sewage. A "Sewage Sludge Hygienisation Plant" of 100 tonnes per day capacity was setup at Shahwadi, Ahmedabad under MoU with Ahmedabad

Municipal Corporation (AMC). The irradiated sludge was mixed with Bio-NPK fertiliser produced by Anand Agricultural University and is supplied to farmers as an organic fertiliser. Now, Indore Municipal Corporation has initiated to set up a plant at Indore.

5.2. Technology for effluent treatment from dyeing and printing mills

Irradiation causes activation for several chemical resins. Based on this concept, irradiation of a cloth dipped in resin helps grafting of resins and helps in capture of dyes used in printing mills. This technology is well suited for cotton dyes. The water obtained is absolutely clean and can be reused within the dyeing units. It helps in reducing the pollution of water bodies in and around textile industries. Even the resin activated filter can be used to remove chromate from chromate contaminated water bodies. A demonstration plant (80,000 liter per day) has been set up in collaboration with the Jetpur Dyeing and Printing Association (JDPA) at the Common Effluent Treatment Plant (CETP) located at Bhadar river bank, Jetpur, Gujarat.

Conclusion

Department of Atomic Energy in India has evolved into a technology powerhouse by developing numerous radiation technologies for societal needs in various sectors such as healthcare, food preservation, agriculture, material science for high tech applications, waste management, etc. For utilisation of these non-power applications and spin off technologies in the area of water, agriculture, food processing and agri-land improvement through urban and rural waste management, DAE has launched AKRUTI (Advanced Knowledge and RUral Technology Implementation) programme to encourage village techno-preneurship based on DAE technologies.

Back cover:

Many birds have made the Indian nuclear power plants their homes because of the lush biological diversity at the sites. Several migrant birds also visit the sites. The photograph is of Gallinago gallinago, a winter migrant from Central Asia to India. Most Indian nuclear power plants come under its distribution range and it is commonly seen in places around Kalpakkam and Kudankulam.

(Source: Fliers of Courtyards, NPCIL)