CORE COURSE ENS18301CR: Natural Resources

Credit IV: Energy resources

1.3. Nuclear Energy

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SUMMARY

Each major technological advance over the last few decades has introduced a new hazard to man, either directly or indirectly. To meet the energy and power demands, man must generate energy from the natural resources existing in the world. Thus, both fossil fuelled and nuclear power stations have been built with the end result of this unwanted wastes from industries. The evolution of technology for generation of electricity is one of the notable development of post world war period where experts/proponents claimed that the energy from nuclear plants would be "too cheap to meter" but much of that optimism has been warning. As opposite to coal and oil, it produces little air pollution. Despite the advantage of nuclear as a clean energy, the big concern is the waste that has resulted from nuclear reaction and if this waste accumulates, it poses a potential hazard to human health as well as the environment. The radioactive wastes from the natural and radiation from anthropogenic or any other sources causes the nuclear hazards. The substantial drawbacks of nuclear power include; 1) contamination of environment with long lasting radioactive materials from accidents at plants and during transportation; 2) health impacts; 3) limited supplies of uranium; 4) high construction costs; 5) waste disposal problems 6) proliferation of nuclear weaponry from high level reactor wastes. With the increasing use of nuclear energy in industry, sciences and the technology, radiation biology will continue to grow but the radiation and releases from the nuclear plants are to be controlled so that risk to the public is minimal.

TEXT

Any undesirable effect caused to the environment due to radioactive substances or radiations is called nuclear pollution. Pollution from radiation is a serious environmental concern arising from pollutants released in the environment through human activities. Nuclear pollution happens when radioactive element comes into the contact with other elements in environment and emits short wave electromagnetic rays which are serious threat to living organisms. Some elements in this world are naturally radioactive while some others are made to be. The radioactive substances present in nature undergo natural radioactive decay in which unstable isotopes with excess protons and neutrons spontaneously give out fast moving particles, high energy radiations or both, at a fixed rate until a new stable isotope is formed. The time that it takes for half way of decaying process is called half-life, and this differs for each radioactive element. It possibly takes up to 4.5 billion years (Uranium 238) and as short as 8 days (Iodine 131). Unstable, radioactive nuclei are called radionuclides. They occur naturally or can be produced by various physical means. The naturally occurring radionuclides are isotopes of heavy elements, from lead (82 protons in the nucleus) to uranium (92 protons in the nucleus).The high energy radiation emitted from radioisotopes remove electrons from atoms and attach them to other atoms, consequently producing positive and negative ion pairs. Such high energy radiations are known as ionizing radiations. The type of radiation emitted from one radioisotope differs from another. Radionuclides release energy either in the form of Gamma rays, Alpha particles and beta particles. These ionization radiations have variable penetration power and ionization (fig.1).

- **Alpha particles** can be **blocked by a piece of paper and human skin**. Alpha particles are fast moving positively charged particles. Alpha radiation is highly ionizing but lacks penetration power.
- **Beta particles** are high speed negatively charged electrons. Beta radiation is somewhat less ionizing but somewhat more penetrating as well. Beta particles can penetrate through skin, while can be **blocked by some pieces of glass and metal.**
- **Gamma rays** are a high energy form of radiation with no mass and no charge. Gamma rays are less ionizing but have extremely high penetrating powers. Gamma rays can penetrate easily to human skin and damage cells on its way through, reaching far, and can only be **blocked by a very thick, strong, massive piece of concrete.**

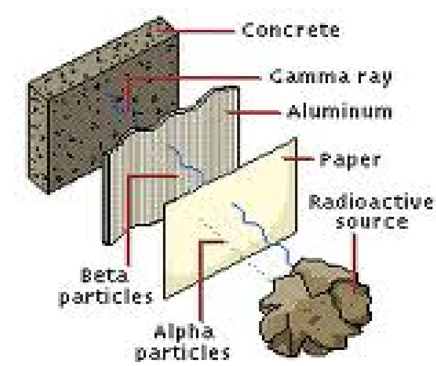


Fig.1.Radiation penetration (source http:// www.xenu.net/archive:

Another type of radioactive emissions is neutron rays. Neutrons are large and uncharged particles that are emitted from radionuclides. The neutron particles are highly penetrating because they have no electric charge. They are neither deflected nor slowed by passage near charged particles. They move in a straight path until they collide with nuclei of other atoms. They can induce radioactivity in non radioactive substances. Neutrons are produced in atomic bombs and nuclear reactors. Major radiation hazards are the result of exposure to gamma rays or neutron rays. All these forms of radiation are called ionizing radiation because they possess enough energy to rip electrons away from atoms, leaving charged atoms called ions and these ions are the primary cause of damage in tissues. Radioactive substances, radiation and the environment are the concerns to a radiation ecologist. There are two important areas of radiation ecology, (I) effects of radiation on organisms in the biosphere, and (ii) the fate of radioactive substances released into the environment. The ratio of a radionuclide in the organism to that of environment is called concentration factor. Radioactive substances when released into the environment are either dispersed or diluted but they may also become concentrated in living organisms and during food chain transfers called as biomagnification. Other than naturally occurring radioisotopes; significant amounts are generated by human activity, including the operation of nuclear power plants, the manufacture of nuclear weapons, and atomic bomb testing.

CAUSES OF NUCLEAR POLLUTION

Nuclear waste and radiation pollution involve any process that emanates radiation in the environment from a number of sources. The most common ones include:

- **Mining and refining of uranium**: Mining of radioactive ores e.g.) uranium and phosphate ores involves the crushing and processing of radioactive ores which generates radioactive by-products. Low-grade uranium ore containing 0.2 % uranium by weight, is obtained by surface or underground mining. After mining the ore undergoes a milling process where it is crushed and treated with a solvent to concentrate the uranium and produces yellow cake (U_3O_8) which is a material containing 70 to 90 % uranium oxide. Naturally occurring uranium contains only 0.7 percent of fissionable U-235, which is not high enough for most types of reactors.

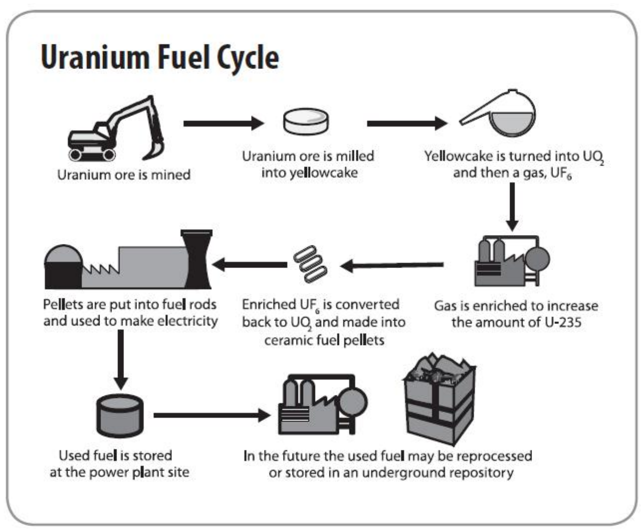


Fig.2. Uranium fuel cycle (source: https://www.e-education.psu.edu/drupal6files/eme444/images/uranium fuel cycle.jpg)

Hence, it is necessary to increase the amount of U-235 by enrichment though; it is a difficult and expensive process. The enrichment process increases the U-235 content from 0.7 to 3 percent. A process known as Fuel fabrication then, converts the enriched material into a powder, which is then compacted into pellets. The fabrication of the elements produces solid, liquid and gaseous wastes (three kinds of radioactive pollutants). These pellets are sealed in metal fuel rods about 4 meters in length which is then loaded into the reactor. As fission occurs, the concentration of U-235 atoms decreases. After about three years, a fuel rod does not have enough radioactive material to sustain a chain reaction and hence, the spent fuel rods must be replaced by new ones. The spent rods are, however, still very radioactive containing about one percent U-235 and one percent plutonium. These rods are a major source of radioactive waste material produced by a nuclear reactor. At each step in the cycle (fig. 2), there is a danger of exposure to harmful radiation and poses several attendant health and environmental concerns

- **Operations conducted by nuclear power stations**: Nuclear power uses of sustained nuclear fission to generate heat and electricity. The nuclear reaction produces highly radioactive waste. The nuclear fuel contains U-235. Nuclear fuel does not burn like fossil fuels but reaction that drives the release of nuclear energy in power plants is nuclear fission, when an atomic nucleus is split apart. Atoms don't split spontaneously. Inside a nuclear reactor U-235 atom undergo fission when they are struck by neutrons and once they split, uranium atoms give off enormous amount of energy (fig. 3-a). U-235 is housed in long fuel rods that are located in the reactor core. U-235 atoms naturally emit neutrons that bombard other uranium atoms, causing them to split. The heat released in during fission is then transferred to water that bathes the fuel rods in reactor core. The heated water around the reactor core heats water in another closed system. In the latter, hot water is converted to steam, which drives a turbine that generates electricity. The steam is then cooled and the water is used again. Most nuclear plants are cooled by water and are called light water reactors (LWRs). Other reactors use coolants such as liquid sodium but operate on the same principle and are called as liquid

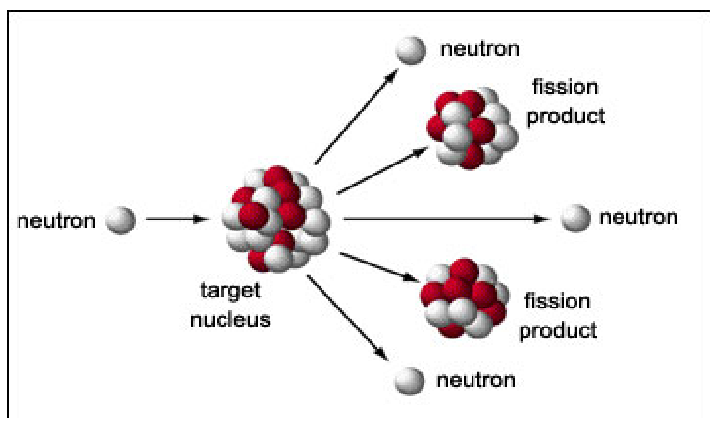


Fig.3. (a) Nuclear Fission (source: www. atomic archive. com/fission/fission1.shtml)

metal fast breeder reactor (LMFBR). The radioactive emissions to the air vary with the type of reactor, they include nuclear fission products and neutron generated nuclides. Gaseous wastes include several radionuclides, viz.Tritium-3, Carbon-14, Argon-85, Krypton-85, Iodine-131 and xenon-137. Liquid wastes contain Tritium-3 and radioactive isotopes of iron, cobalt, etc. Another operation of nuclear power plant involves reprocessing of the spent fuel which includes chemical treatment to separate the reusable components of uranium-235, uranium-238, and plutonium-239 from the waste fission products. In this process gaseous waste fission products such as Tritium-3, Krypton-85 and Iodine -131 as also large quantities of liquid wastes containing half life nuclides and some high activity solid wastes are also produced.

When a U-235 nucleus splits, it produces two smaller nuclei, called daughter nuclei or fission fragments. Over 400 different fragments can form during uranium fission, many of them are radioactive. When U-235 nuclei split, they also release neutrons, which strike other nuclei in the fuel rods, creating a chain reaction (fig. 3-b). The heat generated by fission is so intense that if the chain reaction is not carefully controlled and temperature rise not checked would soon melt the contents of the core and walls of the nuclear reactor with massive leakage of uranium and its many radioactive products and thus send tons of molten slag through the floor of containment building. It is known as meltdown. A full meltdown would be an environmental hazard releasing high levels of radioactivity in the air, soil and both surface as well as groundwater and subsequent storage and processing of these fuel rods with associated high radioactivity poses several problems. Three Mile Island nuclear power plant leakages in U.S.A. in 1979 and meltdown of Chernobyl nuclear power plant in the U.S.S.R. in 1986 are the examples of nuclear plant accidents causing escape of radionuclides in the atmosphere.

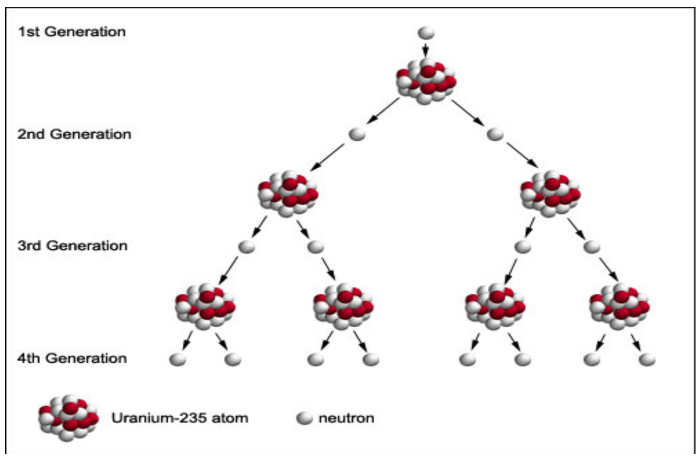
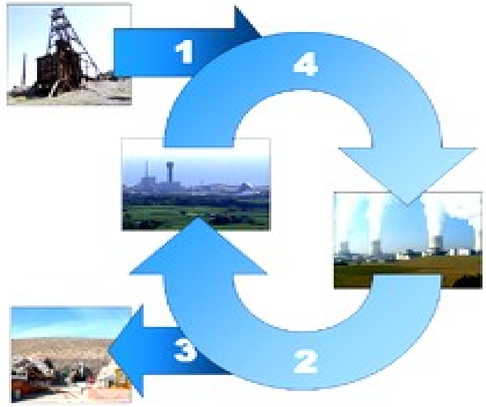


Fig.3. (b) Chain reaction (source: www.atomic archive.com/fission/fission1.shtml)



The nuclear fuel cycle begins when uranium mined, enriched, and manufactured into nuclear fuel, (1) which is delivered to a nuclear power plant. After usage in the power plant, the spent fuel is delivered to a reprocessing plant (2) or to a final (3) for geological disposition. In reprocessing 95% of spent fuel can potentially be recycled to be returned to usage in a power plant (4).

Fig.4.Life cycle of nuclear power plant (Source: http://en.wikipedia.org/wiki/files:nuclear_fuel_cycle png)

- **Nuclear explosions and detonations of nuclear weapons**: Of all the activities concerning nuclear weapons, testing has been the most destructive of human health and the environment. Nuclear explosion is responsible for nuclear pollution which is carried out for performing nuclear tests and for making nuclear weapons (fig.5). China, France, India, Pakistan, Russia, the US and UK have collectively conducted over 2000 nuclear explosions for testing purposes - approximately 500 above ground and the rest underground. Due to this explosion about 15 to 20% of the radioactive particles enter into the stratosphere. Nuclear explosions are very rapid and based on a rough estimate; in an explosion about 50% of the energy goes to the blast, 33% as heat and the rest 17% or so as radioactivity (Wagner, 1971). The nuclear explosion matter is vaporized to hot gas with very high pressure (several billion atmosphere) by heating at very high temperature (10^{8} ^{0}C). An intense shower of many kinds of radiation releases in the atmosphere falls back to the earth in the immediate vicinity of the blast within hours.

Fig.5. Nuclear explosion (source: http://thesilicongraybeard.blogspot.com)

Once they enter into the air, they continue to fall on the earth. The radioactive dust that falls to the earth after atomic explosion is called radioactive fallout. The half life of the radionuclides so produced varies from a few seconds to thousand years. e.g.) strontium-90 with 28 years and caesium-137 with 30 years. Strontium-89 with 50 days and carbon-14 with more than 5000 years.strontium-90, caesium-137 being the most dangerous materials in radioactive fallout from nuclear tests contaminate the environment for many years. It has been estimated that global fallout from nuclear testing will lead to over 2 million cancer fatalities alone, not counting other health effects. (Radioactive Heaven and Earth. IPPNW. Apex Press. New York. 1991). The amount of radioactive fallout produced depends not only on the type and size of the atom bomb but also on the mixing of environmental materials with radionuclides. The radioactive dusts fuse with iron, silica and particulate matters in the vicinity and form relatively insoluble particles. The smaller particles adhere tightly to the leaf tissue which is ingested by the grazing animals and thus the radioactive fallout passes into man through food chain. The best example of fallout is the nuclear bomb attack on Hiroshima and Nagasaki, Japan in 1945 by United States of America during World War II. As a result of nuclear bomb attack, nearly 2, 25,000 people had died as a result of long-term exposure to radiation from the bomb blast within 5 years of attack due to radiation effect and cancer. Moreover, the nuclear tests which are conducted under the ground or under oceans also release radiation. Earlier, explosive tests of nuclear weapons have been conducted in the air, on ground, underground or under the sea. Most of these tests with exception of underground tests produce significant quantities of radionuclides e.g. C-14, Sr-90, I-131, Cs-137.

- **Defense weapon production**: In addition to the potential damage of a nuclear weapon explosion, there is also the issue of existing environmental harm caused by weapon production. Production of nuclear weapons involves the generation of large quantities of waste material and contamination of surrounding areas. This process generates large quantities of waste that oftentimes ends up in oceans, rivers, and soil. Nuclear weapons produce nuclear waste called Transuranic (TRU) waste. TRU materials have been generated in the U.S. since the 1940's. Most of this waste originates Clean-up and containment of radioactive products that are dangerous for thousands of years presents the biggest challenge. But there are also risks in dismantlement of nuclear weapons including hazards to workers and environmental risks associated with non-nuclear aspects such as missile destruction. For example, pursuant to the Intermediate Range Nuclear Forces Treaty, hundreds of Pershing missiles were burned in the open air or exploded on a test stand at the Pueblo Army Depot in

Colorado, United States. These procedures release clouds of toxic hydrochloric acid when the missiles solid fuel combines with moisture.

- **Decommissioning of nuclear weapons:** The decommissioning of nuclear weapons causes slightly more radioactive pollution than in the production, however, the waste (alpha particles) is still of low risk and not dangerous unless ingested.
- **Nuclear waste handling and disposal**: Transportation of nuclear wastes from one place to another by modes of transportation (air, land, water, sea) possibly brings serious hazards to the environment if they are not maintained carefully. Nuclear wastes may generate radiation over long period of times. The radioactivity may contaminate and propagate through air, water, and soil as well. Thus, their effects may not be easily distinguishable and are hard to predict. Additional, some nuclear waste location may not be identified. The main problem with radiation waste cannot be degraded or treated chemically or biologically. The decaying process of radioactive waste takes a very long time in progress because some radioactive wastes have a half-life of more than 10,000 years and are dangerous in great amount of time. The low level wastes from power plants and other facilities including hospitals and laboratories are hazardous for about 300 years and high level wastes can be dangerous for tens of thousands of years. Thus, the only options is to contain the waste by storing it in tightly closed containers shielded with radiation-protective materials or, if containing is not possible, to dilute it. The waste may also be contained by storage in areas remote from biological habitats with little or no life e.g.) remote caves or abandoned salt mines. However, in time, the shields (natural or artificial) may be damaged. Additionally, the past waste disposal practices may not have used appropriate measures to isolate the radiation. Thus, such areas need to be carefully identified and access restrictions promptly imposed.
- **Medical waste**: A number of radioactive isotopes are used in medicine, either for treatment or diagnostics. Radioactive medical waste tends to contain beta particle and gamma ray emitters. In diagnostic nuclear medicine a number of short-lived gamma emitters such as technetium-99m are used. These can be left over a short period after which they are able to be disposed of as normal waste. X-rays are the greatest man made radiation. X-ray machines are used for diagnostic purposes and in radiotherapy. X-rays penetrate the human body as gamma rays do. X-ray exposure causes cumulative effects on the human beings.

EFFECTS OF NUCLEAR POLLUTION

1. **Biological effects of ionizing radiation:** Ionization radiations bring about more dangerous effects than other toxicants. Most serious

disorders are caused by the radiations escaped from nuclear power plants and nuclear explosions. Their effects may continue in subsequent generations. The principle effect of exposure of the whole body to penetrating ionizing radiation is the shortening of life of the exposed organisms. The length of life is shortened .Studies have shown that the health effects due to radiation are dependent on the level of dose, kind of radiation, duration of exposure and types of cells irradiated. Radiation effects can be somatic or genetic. They bring about the following two types of undesirable effects in organisms.

a. **Somatic effects:** These are the direct results of action of radiation on the function of body cells, tissues and organs. It causes damages to cell membranes, mitochondria and cell nuclei resulting in abnormal cell functions, cell division, growth and death. Radiologists, uranium mine workers and painters of radium dials suffer most. The somatic effects may be immediate or delayed. High radiation exposures have much toxicity and can kill animal quickly. A dose of 400 to 500 roentgen on whole body is fatal in about 50% cases of man, and 600 to 700 in practically every case, The victim declines in vitality and dies from anemia, infection and haemorrhage. Parts of body differ in sensitivity. The most sensitive tissues from acute doses are intestines, lymph nodes, spleen and bone marrow. The radiation destroys the body’s immune response. The effects of low penetrating radiation are less severe than the penetrating ones. In delayed effects the patient may survive for months or years. Delayed effects of radiation include eye cataracts, leukemia, malignant tumors, cardiovascular disorders, premature ageing and reduced life span. Diagnostic x-ray exposure of pregnant women may increase the risk of cancer in child. More evidence of degree and kind of damage from radiation come from studies of Nagasaki and Hiroshima survivors.

b. Genetic effects: Both background natural and manmade radiation bring about the genetic effects. Studies on Drosophila have shown that mutation rates go very high due to radiation exposures. Background reactions differ in different parts of the earth. Most genetic effects are brought about by man-made radiations, most important of which are exposure during medicare and power plants. People in industry, research and medicine using radionuclides are exposed more than others. The greatest damage is in dividing cells, chiefly the gonads. The effects include mutation which is changes in genetic makeup of cells where these effects are mainly due to the damages to DNA molecules (fig.6), lethal effects on egg or embryo. People suffer from blood cancer and bone cancer if exposed to doses around 100 to 1000 roentgens. Instantaneous deaths can occur on exposure in the event if disasters are many. The intensity of radiation affects the rate of mutation. Generally higher animals are more susceptible to genetic damage than lower animals as insects. Genetic effects also occur in plants.

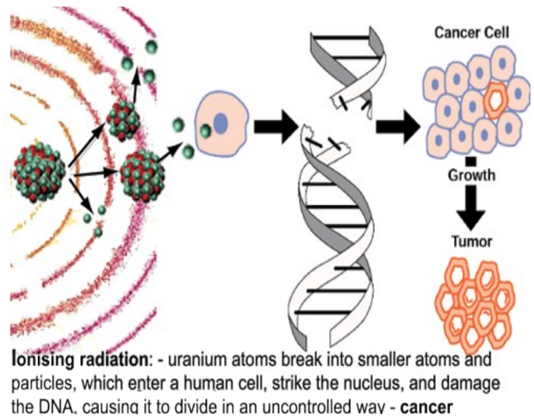


Fig.6. (Source: http// Nuclear-news.net) 2012/6/22)

Example of effects on the human health: The Chernobyl explosion led to increased prevalence of cancer in young children in Belarus, the Russian Federation, and the Ukraine. According to the Greenpeace 2006 report, “Chernobyl Catastrophe Consequences on Human Health,” over 2 billion people have been exposed to the radioactive fallout, which will result in 250,000 cases of cancer, nearly half of them fatal. Ionization radiations can cause brain damages. High exposure to radiation early on in gestation can have damaging effects on the brain, notes the U.S. Centers for Disease Control (CDC). Infants between the eighth and 15th weeks of pregnancy who were exposed to the atomic bombs dropped on Hiroshima and Nagasaki during World War II were discovered to have a greater incidence of brain damage, with side effects including lower IQs and, in some cases, severe mental retardation.

2. EFFECTS ON THE ENVIRONMENT

The environmental impact of nuclear power results from the nuclear fuel cycle, operation, and the effects of accidents. The possibility of over-heated fuel releasing massive quantities of fission products to the environment can cause catastrophic risks to the environment.

a. **Contaminated water:**
   According to World Health Organization (WHO), nuclear accidents may produce fallout which can pollute water supplies for years after the incident. The 1986 explosion of a nuclear generator in Chernobyl (Ukraine) created a large radioactive cloud which polluted existing water supplies and produced contaminated rain in nearby countries.
b. **Increase in water temperature:**
   Nuclear power plants release heat into water like thermal power stations and it is obvious that the temperature of water in the area of nuclear power station is higher than without it which disturbs the balance of water evaporation. Also the amount of salt in water increases. Such changes lead to extinction of some species of animals.
c. **Contaminated soil and plants:**
   Nuclear radiation can contaminate soil which leads to plants which poses a health threat to individuals. Researchers explored the Marshall Islands, an area widely known for nuclear bomb testing by the U.S. military in the 1950s and 1960s. They found that current soil samples and local foods, including coconut meat, contained radiation levels significant enough to pose a health risk to individuals.

CASE STUDY

Reactor Accidents (Chernobyl Accident)

The power plants are designed in a way that there is no leakage of radioactive materials in any form. However, no nuclear plant is contamination proof. These problems have reached a climax with two accidents - Three Mile Island in US in 1979 and Chernobyl in Ukraine (erstwhile USSR) in 1986. These two major accidents have greatly shaken the public's confidence in the inherent safety of nuclear power. Significantly both the accidents were due to human

Fig.7. (Source: http://cdn.theatlantic.com/static/infocus/chernobyl25/s_c03_51952990.jsource:Nuclear-news.net 2012/6/22)

error. The Chernobyl accident was relatively more serious. In the early morning hours of April 26, 1986, residents of the Ukraine village of pripyat saw a horrifying sight. A glowing foundation of molten nuclear fuel and burning graphite was spewing into the dark sky through a hole in the roof of the Chernobyl Nuclear Power only a few kilometres away. The villagers were witnessing the worst possible “meltdown” of the nuclear fuel and rupture of the containment facilities, which released high amounts of radioactivity into the environment (fig.7). The accident, was as a result of a risky experience that was undertaken by the plant engineers with violation of a number of safety rules and operational procedures. They were testing whether the residual energy of a spinning turbine could provide enough power to run the plant in an emergency shutdown, if off-site power were lost. To conserve the small amount of electricity being generated, the emergency core cooling pumps and other safety devices were disconnected without knowing that the reactor was dangerously unstable under such conditions. At first the core began to rise and then faster and faster. The operators tried to push the control rods into the core to slow down the reaction, but the graphite pile had been deformed by the heat that the rods didn’t go in. Chemical explosion ripped open the fuel rods and cooling tubes. Molten uranium fuel puddle in the bottom of the bottom of reactor that created a critical mass that accelerated the nuclear fission reactions. It is estimated that about 7,000 kilograms of highly radioactive material containing iodine-131, strontium-90 and caesium-137 and plutonium as well as other nuclides with a total activity of 50-100 million curies were released in the explosion. One clear example of effects was seen in children in Belarus, where thyroid cancers have increased a hundred-fold since 1986. Childhood leukaemias and some autoimmune disease also appear to be more prevalent in highly contaminated areas. Opponents are of the opinion that we should learn from these tragedies and abandon this dangerous technology.

QUIZ

1) Which of the following is the best definition for the term radionuclide
   a. the nucleus of any atom
   b. the nucleus of an atom that contains more than 75 neutrons
   c. an atom whose nucleus absorbs radiation
   d. an atom whose nucleus is unstable

2) Low-grade uranium ore contains what percentage of uranium by weight
   a. 1 %
   b. 0.2 %
   c. 2%
   d. 6%
3) The enrichment process of U-235 increases its fissionable content from 0.7% to
   a. 1%
   b. 3%
   c. 5%
   d. 7%
4) Chernobyl accident in USSR took place in the year
   a. 1979
   b. 1986
   c. 1954
   d. 1965
5) Three Mile Island accident in US took place in the year
   a. 1982
   b. 1974
   c. 1979
   d. 1950
6) The term nuclear energy is closely associated with which one of the following
   a. Nuclear fusion
   b. Nuclear fission
   c. Bombardment reaction
   d. Radioactive decay
7) The half life of Iodine-131 is
   a. 2 days
   b. 8 days
   c. 5 years
   d. 12 years
8) The nuclear fuel used in nuclear reactors contain
   a. U-235
   b. I-131
   c. C-14
   d. Cs-137

9) The ratio of a radionuclide in the organism to that of environment is called
   a. Concentration factor
   b. Biomagnifications
   c. Bioaccumulation
   d. Bioavailability

10) Nuclear Energy is derived by
   a. combustion of atoms of U-235
   b. fission of atoms of U-235
   c. fusion of atoms of U-235
   d. the breaking of U-235 bonds

11) Strontium of radioactive-fallout is
   a. Sr-80
   b. Sr-85
   c. Sr-90
   d. Sr-95

12) Non-ionizing radiations with specific biological effects are
   a. X-rays
   b. UV-rays
   c. β-rays
   d. Gamma rays

13) Which of these is most ionizing
   a. α-rays
   b. β rays
   c. neutron rays
   d. γ-rays

14) Environmental pollution which can cause birth defects
   a. Radioactivity
   b. SO_2
   c. Smog
   d. CO

15) Ultimate environmental hazard to mankind is due to
   a. Nuclear pollution
   b. Air pollution
   c. Water pollution
   e. Noise pollution

Key: 1) d; 2) b; 3) b; 4) b; 5) c; 6) b; 7) b; 8) a; 9) a; 10) b; 11) c; 12) b; 13) c; 14) a; 15) a.

GLOSSARY

Atom: Basic component of matter. An atom is the smallest part of an element having all the chemical properties of that element. An atom consists of a nucleus (that contains protons and neutrons) and surrounding electrons.

Beta particles: Negatively charged particle (an electron) emitted in radioactive decay of unstable atoms. A beta moves faster than an alpha and can be stopped by a thin piece of aluminum or a short span of air.

Curie (Ci): A unit representing the rate of radioactive decay. 1 Ci = 3.7×10^{10} disintegrations per second.

Decommissioning: Closing a nuclear power plant after it has operated about 40 years

Dose: Amount of radiation or energy absorbed (often measured in mrem).

Fissile: Material that will fission, i.e. split into two or more lighter materials, upon absorbing a neutron.

Fission products: The atoms that remain when uranium is split in a nuclear reactor. Fission products are usually radioactive.

Heavy water: Water in which the hydrogen atoms contain one neutron in their nucleus in addition to the characteristic proton.

Ionizing radiation: Any electromagnetic or particulate radiation capable of direct or indirect ion production in its passage through matter.

Non-ionizing radiation: Long-wavelength electro-magnetic radiation.

Isotopes: Atom of the same element but with a different mass number. Isotopes contain the same number of protons in their nucleus (hence, the same chemical properties), but different numbers of neutrons, e.g. isotopes of carbon are C-12, C-13, and C-14.

Moderator: Substance that slows down neutrons so they are more likely to cause fission.

Neutrons: One of three basic particles in all atoms except hydrogen. Neutrons are located in the atom nucleus, are electrically neutral, and each has mass about equal to a proton.

Rad: A unit of absorbed ionizing radiation which results in the absorption of 100 ergs of energy per gram of medium. 1 Rad = 0.01 Gray.

Radioactive half-life: The time required for half the atoms of a radioactive isotope to decay to a more stable isotope

Radioactivity: Spontaneous release of subatomic particles or gamma rays by unstable atoms as their nuclei decay.

Radiography: Use of ionizing radiation to produce shadow images on a photographic film. Some of the gamma or X-rays pass through an item being evaluated while others are partially or completely absorbed by more opaque parts of the item and cast a shadow on the photographic film.

Rem: A unit of the biological effectiveness of absorbed radiation, which is equal to the radiation dose in rad multiplied by a biological weighting factor, which is determined by the particular type of radiation. 1 rem = 0.01 Sievert.

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