35
Nuclear Waste and Their Disposal

35.1 INTRODUCTION

The nuclie of certain heavy atoms are unstable. They undergo spontaneous changes during which they emit fast moving particles and/or high energy electromagnetic radiation. This process is called **radioactivity**. This radiation is called **ionizing radiation** because it can hit and remove one or more electrons from atoms and convert them into positively charged ions.

Exposure to any ionizing radiation can damage living cells in the human body. The threat of radioactive pollution to humans and the environment has increased after the discovery of artificial radioactivity particularly due to the development of nuclear weapons and installation of reactors for generating nuclear energy. In this unit, we shall deal with the possible threat to human health and environment due to nuclear radiations both from natural and anthropogenic (man-made) sources and methods for the safe disposal of nuclear waste materials.

35.2 OBJECTIVES

After reading this lesson you will be able to :

- list various radioactive sources.
- account for the release of radioactive products resulting from nuclear waste and nuclear accidents.
- enumerate the ill-effects of radiation on human body.
- list the various preventive measures of radioactive pollution.
- list the various regulations regarding safety measures for radiation exposure.

35.3 IONISING RADIATIONS AND RADIOACTIVE DECAY

The two types of ionizing particulate radiation are alpha (α) particles (positively charged

matter consisting of two protons and two neutrons) and beta (β) particles (negatively charged electrons). The most common ionizing electromagnetic radiation given out by radioactive materials is high-energy γ-rays (gamma). These rays are even more penetrating than X-rays.*

Radioactive nuclei spontaneously emit high energy electromagnetic radiations (γ-rays) or subatomic particles (α or β particles) or both and gradually change into another radionuclide or simple element. This is known as **radioactive decay**.

35.4 VARIOUS SOURCES OF RADIOACTIVE POLLUTION

Radioactive elements occur naturally in the environment from the weatherings of atomic minerals. Living organisms are continuously exposed to a variety of radiation sources which are classified as natural sources of radiation and anthropogenic sources of radiation

35.4.1 Natural Sources of Radiation

(i) **Weathering of atomic minerals** : During mining of uranium, radon gas is constantly released in the air. The parent of radon-222 ($t_{\frac{1}{2}}$ = 3.82 days) is radium 226 which has a half-life of 1602 years and is widely distributed in rocks, sediments and soils along with isotopes of uranium. It is, therefore, impossible to avoid exposure to ionizing radiation from these sources which is also known as natural or background radiation.

(ii) Other sources include cosmic rays which are high energy ionizing electromagnetic radiation from outer space;

(iii) Naturally occuring radioisotopes such as radon-222 found in soil, bricks and in concrete floor is another source of radiation. Radioactive elements which occur in the lithosphere comprise uranium, thorium, radium, isotopes of potassium (K-40) and carbon (C-40).

Potassium-40 contributes radioactivity to all potassium containing systems in the soil. Crops grown on such soil contain radioactive elements like carbon-14 and potassium-40. Water gets contaminated with various radionuclides when it runs through soils and rocks containing radioactive minerals. We live in an environment of natural radiations but they are only rarely harmful as the radiation level is generally quite low.

35.4.2 Anthropogenic Sources of Radiation

We receive exposure to ionizing radiation as a consequence of various human activities.

(i) Diagnostic medical tests : Most of exposure to radiation is from dental and X-rays and other tests involving ingestion of radioactive isotopes administered to patients during radiation therapy.

(ii) Nuclear Tests : Nuclear explosion tests especially when carried out in the atmosphere are a major cause of radiation pollution and are responsible for increasing the background level of radiation throughout the world. During atmospheric nuclear explosion tests, a number of long-lived radionuclides are released into the atmosphere. This **radioactive dust** (also known as **radioactive fall out**) becomes suspended in air at a height of 6 to 7 km above the earth's surface and is dispersed over long distances by winds from the test site. These radionuclides often settle down by rain and are mixed with soil and water. From there they

* X-rays are a form of ionizing radiation but these are not released by radioactive materials. They also possess high energy.

can easily enter the food chain and finally get deposited in the human body where they pose serious health hazards. Some of the radioactive isotopes given off during nuclear tests affect the human body.

India exploded its nuclear device (equivalent to 12 kilotons of Tri Nitro Toluene) in an underground tunnel at a depth of 107 meters in the Thar desert near Pokharan in 1974. No radioactivity is said to have been released into the surroundings. Again in May, 1998 India conducted nuclear tests without any release of radioactivity into the surroundings.

(iii) Nuclear Reactors : Radiations leak from nuclear reactors and nuclear facilities even when they are operating normally. It is often feared that even with the best design, proper handling and techniques, some radioactivity is routinely released into the air and water.

> **Nuclear Reactor is a set up from which nuclear energy is released continuously under controlled conditions. A nuclear reactor is used to generate power.**

However, dangers of radiation leakage is from some real possibility of accidents that could result in the emission of large quantities of ionizing radiation. Such accidents took place at the 'Chernobyl nuclear power plant' in USSR in 1986 and at the 'Three Mile Island Power Plant' in USA in 1979.

35.5 RELEASE OF NUCLEAR RADIATION FROM NUCLEAR WASTES

35.5.1 Mining of Uranium Ores

Naturally occuring uranium slowly decays into other products which are also radioactive. Therefore, large volume of waste material that remains after uranium mining and milling process is also a source of ionizing radiations. This waste occurs as a liquid or as powder and called 'debris' or 'tailings'. The tailings emit radioactive radon-222 gas for hundreds of thousands of years and can pollute local ground water by seepage. The solid tailings can also get dissolved by rainfall and mix with the ground water. The use of solid tailings as landfill on which buildings are constructed can cause problems due to radiation by release of radon gas produced by the decay of uranium-238. Radon can diffuse through rocks and soils into the atmosphere. Once the radon reaches the atmosphere it can be breathed in. The transformation into lead is very significant because the solid radioactive particles are trapped in the lungs and are acutely harmful.

35.5.2 Nuclear Wastes

When uranium-235 nuclei split in a nuclear reactor, they break into fission products

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n + \text{Energy}$$

which are also intensly **radioactive**. Since one uranium atom splits into two radioactive products, there is a doubling of the number of radioactive atoms on earth. Furthermore.

uranium-235 has a half-life of more than 700 million years. Some of its fission products have shorter half-lives and decompose much faster than uranium and emit higher levels of radiation.

There is no method by which we can increase or decrease the decay of these products. The wastes of nuclear reactor emit dangerous radiations for thousands and thousands of years. Since it is not possible to destroy these radionuclides, they must be stored somewhere on this earth in order to cause least harm to humans.

Plutonium-239 is another example of nuclear waste problem. The plutonium-239 isotope is produced as a by-product during uranium fission. It is an alpha particle emitter and has a long half-life of 24000 years. After about 1000 years or more, the main radioactivity from fuel rods of the nuclear reactors will be from plutonium and other such heavy elements, since by then most of the other nuclides produced in fission and having much shorter half-lives will have decayed to a large extent. Plutonium is one of the deadliest poisons known. It does not occur naturally on earth. This element is produced either in nuclear reactors or in nuclear weapons programme. The plutonium produced today will have to be taken care of for thousands of years by our future generations. The general approach in dealing with radioactive wastes is to concentrate and contain as much radioactivity as possible. Effluents containing only very low level of radioactivity is discharged into the environment.

35.5.3 Nuclear Accidents

Nuclear fission converts some fuel in the reactors to radioactive fragments. These reactions produce a lot of heat and therefore the core of the reactor containing fuel rods has to be cooled by water circulation to avoid a meltdown of the fuel rods. If a meltdown happens by accident, it will release large quantities of highly dangerous radioactive materials in the environment. To avoid this type of very serious mishap nuclear reactors are designed to have a number of safety features and it is very unlikely that a reactor would blow up.

Although a core meltdown is highly unlikely, but it is possible. For example, the loss of coolant due to some material failure, would allow the reactor core to overheat and eventually meltdown the fuel rods. Another possibility is the build up of some gas or steam inside the reactor vessel which would blow off the top and release large clouds of radioactive materials in the atmosphere resulting in death and injury to thousands of people.

The accidents of 'Three Mile Island' plant in Middletown (U.S.A.) in 1979 and at Chernobyl nuclear power plant (U.S.S.R.) in 1986 were the worst disasters in the history of nuclear power industry. In both incidents, a series of mishaps and errors resulted in the overheating of the nuclear core. In both cases radiation was released in the atmosphere. The leakage from the 'Three Mile Island' nuclear reactor has been claimed to be very low with no immediate injuries to workers or people. But the leakage at Chernobyl was very heavy causing death to few workers and radiation was spread over large areas scattered all over Europe. People of the city had to be evacuated to safer places and the plant has been closed down. Nuclear scientists, however, feel that such like incidents can be avoided in future by improving reactor design and better operator training.

INTEXT QUESTIONS 35.1

1. What happens when a neutron strikes uranium-235?

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2. Why is it impossible for a nuclear reactor to blow up like a bomb? Explain.

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3. What is the possible hazard to humans and the environment from nuclear reactors?

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4. Name any of the two sources of radioactivity in nature.

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5. Name the three man-made or anthropogenic sources that release radioactivity.

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6. What is radioactive fall out?

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35.6 BIOLOGICAL EFFECTS OF IONIZING RADIATION ON THE HUMAN BODY

Ionizing Radiation has been found to produce : birth defects, mutations and tumors (UV causes skin tumor).

In the last few decades, number of people being exposed to ionizing radiation has increased tremendously, especially people involved in the mining of uranium ores, patients treated with γ-radiations, technical people using X-rays and other radioactive isotopes. Before the dangers of radiation on human body were known, workers dealing with radioactive materials were careless and suffered from various types of cancer. Early workers who used phosphorescent radium paint on the dials of watches suffered from bone tumors in 1920s.

35.6.1 Types of Radiation Damage

Exposure to any type of ionizing radiation (α and β particles, γ-rays and X-rays) can prove harmful and even lethal. The two types of effects are : (i) **genetic** and (ii) **nongenetic** or **body damage**. In genetic damage, genes and chromosomes get altered. Its effect may become visible as deformations in the offsprings (children or grandchildren). Alterations or breaks in the genetic material that is DNA (Deoxyribonucleic acid) - the molecule containing genetic information, is called mutation. In nongenetic effects, the harm is visible immediately in the form of birth defects, burns, some type of leukemia, miscarriages, tumors and cancer of one or more organs.

35.6.2 Extent of Damage

The extent of damage depends on the following factors :

(i) the time of exposure
(ii) the intensity of radiation
(iii) the type of ionizing radiation (its penetration power)
(iv) whether the radiation is emanating from outside or inside the human body.

Radioactive pollution is different from other forms of pollution of air, water and soil in a

manner that it not only affects the health of an individual (non-genetic) but can also bring about physiological changes in the future generations (genetic effects). Table 35.1 shows the effects of different radiations on the body. These radiations reach human system from natural and anthropogenic sources.

TABLE 35.1

Type of radiation	Effect on the body
α particles	Generally cannot penetrate the skin. But if their source is inside the body, they can cause damage to bones or lungs.
β particles	Can penetrate the skin but cannot damage the tissues. They can cause damage to skin and eyes (cataract).
γ radiation	Can easily penetrate the body and pass through it. They cause damage to cell structure.
X-rays	Can travel very far and pass through the body tissues except bones. They can cause damage to the cells.

Alpha (α) and beta (β) particles can cause burns to skin on high level of exposure from outside but they cannot penetrate the skin to cause internal damage. However, if a radioactive isotope which can emit alpha or beta particles is inhaled or ingested in the body the particles can then cause serious damage to nearby tissues. They may affect the replication of cells and induce tumor formation. The damage inside the body from beta particles is lower than that from the alpha particles of the same energy. Gamma (γ) rays and high energy neutrons are highly penetrating that they pass through the body easily and can cause cellular damage both from outside or inside the body.

35.6.3 Effect of Dose and Time of Exposure

Small doses of ionising radiation over a long period of time cause less damage to human health than the same dosage given all at once. This is due to the fact that human body can make small repairs by itself over some period. Exposure to a large dose over a short time span can prove highly damaging or may even cause death. Rapidly growing tissues of embryo are very sensitive and therefore pregnant women should avoid exposure to radioactivity and X-rays unless they are very essential. Although the medical use of X-rays may involve very low levels of radiation but even such exposures if carried out frequently can result in a significant increase in the dose of ionizing radiation and involves definite risks. The use of radio-isotopes and gamma ray irradiation for cancer treatment can lead to fairly high dosages of radioactivity.

An increase in the altitude, where an individual lives determines the dose received from cosmic radiation. For example, an increase in an altitude of 2000 meters doubles the dose of radiation due to cosmic rays from outer space. The effect of radiation may be immediate or delayed.

INTEXT QUESTIONS 35.2

1. Outline the types of damages to humans on exposure to ionizing radiation.

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2. What were the two accidents in the past which led to high radioactive leakage.

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35.7 PREVENTIVE MEASURES FROM NUCLEAR RADIATION

The following preventive measures may be adopted to reduce the effects due to both natural and artificial radiations:

i) Atomic explosions should not be carried out in the atmosphere.
ii) In nuclear reactors, closed cycle coolant system may be employed, so that no radiation leakage through coolant can take place.
iii) Radioactive wastes generated by nuclear reactors or from nuclear weapons programme must be disposed in a manner that they will do the least harm. First, the wastes may be stored at some place temporarily to allow for the initial, very intense. radioactivity to die down by natural decay. Nuclear wastes should always be sealed in double-walled tanks so that no leaks may take place. In the second stage, some useful isotopes generated during fission in the reactors may be recycled in reprocessing plants. Finally, a permanent storage space for the wastes in geologically stable underground deep mines showed be established. It has been suggested that these wastes may be stored till the wastes are reduced to the same radioactivity level as that of a natural uranium mine.
iv) Production and use of radioisotopes should be minimum and only for very essential use because radioisotopes once produced cannot be destroyed by any means except by the passage of time.
v) The number of nuclear installations should be minimised so as to limit the emission of radiopollutants.
vi) Fission reaction should be minimized.
vii) In nuclear mines, wet drilling may be used and tailings properly sealed and protected for radiation leakage.
viii) Industrial wastes contaminated with radionuclides be disposed carefully in specially built tanks.
ix) Working places where radioactive emissions are possible should have high chimneys and good ventillation system.
x) In areas where there is a risk of radon leakage from underground, radon concentrations be monitored and protection measures be installed in buildings and homes.

35.8 REGULATIONS REGARDING SAFETY MEASURES

The executive agency for all activities related to atomic energy is the Department of Atomic Energy (DAE) which was established in 1954. The sites for nuclear installations are chosen with safety parameters in view. A number of physical barriers are designed which would have to be broken down for any significant amount of radiation to escape from the reactor. The radiation dosage received by workers are monitored on a monthly basis. The Atomic Energy Regulatory Board (AERB) has fixed the dose limit to 30 millisievert (mSv) for workers. This is in agreement with the limit set up by International Commission on Radiological Protection (ICRP).

The Atomic Energy Regulatory Board, an autonomous body of Atomic Energy Commission, carries out all regulatory and safety functions as envisaged under the Atomic Energy Act, 1962 covering all establishments of Department of Atomic Energy. It is also empowered to take decision with regard to site selection, design, construction and commissioning, operation etc. of all nuclear installations.

INTEXT QUESTIONS 35.3

1. What is the concentration of uranium-235 for use as a fuel in nuclear reactors ?

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2. Explain why the daughters of radon-222 are more dangerous for health than radon itself.

   .....

3. How can we safeguard ourselves from radiation originating from tailings?

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35.9 WHAT YOU HAVE LEARNT

- Nuclear radiations are emitted in the atmosphere through (i) natural and (ii) man-made sources.
- Radiations due to natural sources include uses of uranium and other radioactive elements, which after disintegration yield other radioactive isotopes. The prominent source is radon-222 gas.
- Man-made sources of radiation include (i) medical diagnostic tests using radioisotopes. (ii) nuclear tests conducted in the atmosphere (iii) nuclear reactors for research and power.
- Radiations are released in the atmosphere in different ways : (i) radioactive waste from uranium mines called 'tailings' (ii) nuclear wastes left behind by nuclear reactors (iii) products of nuclear reactions such as plutonium-239 (iv) nuclear accidents.
- Ionising radiations can cause mild to very serious effects on the health of humans on exposure and may even lead to death.
- Various steps have been suggested by which radiation leakage can be minimized.

35.10 TERMINAL EXERCISE

1. What type of radiations are called ionizing radiation?

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2. Which type of radiations are damaging to human health?

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3. Define the term 'Background Radiation'?

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4. What are the different man-made sources of radiation?

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5. What are the various sources of radiation from nuclear wastes?

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6. What are the effects of ionizing radiation on human health?

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CHECK YOUR ANSWERS

INTEXT QUESTIONS 35.1

1. Uranium-235 is split into two fission products with the production of three neutrons and lot of energy. The split products are also radioactive. The reaction is known as a nuclear fission reaction.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n + \text{Energy}$$

2. The nuclear fuel that is used in a reactor contains a low concentration of fissionable U-235 (only 3%). Since the critical mass required for a self sustaining fission reaction is not available the probability of nuclei hitting fissionable nuclei is low. The reaction continues in a slow fashion. Also the coolants are used to slow down the reaction.

3. The environment hazards from reactors include :

i) the possibility of a serious accident that releases radioactivity in the atmosphere.

ii) the possibility of small radiation leakages even during normal working conditions.

iii) most importantly the problem of radioactive waste disposal.

4. Weathering of minerals, cosmic rays from outer space, radioactive elements occuring in nature. (Any two)

5. Nuclear waste, nuclear reactors, nuclear accidents.

6. Radionuclides released in the atmosphere during nuclear tests.

INTEXT QUESTIONS 35.2

1. Refer to section 35.6
2. Refer to section 35.5.3

INTEXT QUESTIONS 35.3

1. The concentration of fissionable uranium-235 in the reactor fuel is 3% and 97% is non fissionable uranium-238. The concentration of U-235 in bomb grade material is required to be above 85%.

2. Radon-222 (g) when inhaled inside the body quickly disintegrates into solid radioactive lead-210 which has a long half-life of 22.3 years and emits ionizing radiations causing damage to nearby tissues.

3. Wet drilling may be used and tailings properly sealed and protected from radiation leakage.

35.11 TERMINAL EXERCISE

1. α and β particles, γ and X-rays are called ionizing radiations because they have very high energy and are able to remove one or more electrons from atoms which they may hit and convert these atoms into positively charged ions.
2. All ionizing radiations discussed in question-1, and ultra-violet radiation can cause damage to human health.
3. 'Background radiations' refer exposure to high energy radiations from outer space, and from natural substances such as uranium found in rocks and soils.
4. Read section 35.4.2
5. Read section 35.5
6. Read section 35.6.