1. Introduction

The biological effects of radiation are terms in their effect on the living cells. These effects depend on the type of cell, the amount and type of radiation. Consequently, biological effects of radiation on living cells may result in three outcomes: (1) injured or damaged cells repair themselves, resulting in no residual damage; (2) cells die, much like millions of body cells do every day, being replaced through normal biological processes; or (3) cells incorrectly repair themselves resulting in a biophysical change.

High doses can kill so many cells that tissues and organs are damaged immediately. This in turn may cause a rapid whole body response often called acute radiation syndrome. The higher radiation dose, the sooner effects of radiation will appear, and the higher probability of death. This syndrome was observed in many atomic bomb survivors in 1945 and emergency workers responding to the 1986 Chernobyl nuclear power plant accident.

All people are chronically exposed to background levels of radiation present in the environment. Many people also receive additional chronic exposures or relatively small acute exposures. For populations receiving such exposures, the primary concern is that radiation could increase the risk of cancers or harmful genetic effects. The probability of a radiation-caused cancer or genetic effect is related to the total amount of radiation accumulated by an individual. Based on current scientific evidence, any exposure to radiation can be harmful (or can increase the risk of cancer); however, at very low exposures, the estimated increases in risk are very small. For this reason, cancer rates in populations receiving very low doses of radiation may not show increases over the rates for unexposed populations.

2. Exposure and Risk

Radiation and radiation emitters (radionuclides) can expose the whole body (direct exposure) or expose tissues inside the body when inhaled or ingested.

The health effects of alpha particles depend heavily upon how exposure takes place. External exposure is of far less concern than internal exposure, because alpha particles lack the energy to penetrate the outer dead layer of skin. However, if alpha emitters have been inhaled, ingested (swallowed) or absorbed into the blood stream, sensitive living tissue can be exposed to alpha radiation. The result of biological damage increases the risk of cancer; in particular, alpha radiation is known to cause lung cancer in humans when alpha emitters are inhaled.

External exposure to beta particles is a hazard, because emissions from strong sources can redden or even burn the skin. However, emissions from inhaled or ingested beta particle emitters are the greatest concern. Because they are much smaller and have less charge than alpha particles, beta particles generally travel further into tissues. As a result, the cellular damage is more dispersed.

Both external and internal exposure to gamma-rays or x-rays is of concern. Gamma-rays can travel much farther than alpha or beta particles and have enough energy to pass entirely through the body, potentially exposing all organs.

The types of effects and their probability of occurrence can depend on whether the exposure occurs over a large part of a person's lifespan (chronic) or during a very short portion of the lifespan (acute).

2.1 Chronic Exposure

Chronic exposure is continuous or intermittent exposure to low levels of radiation over a long period of time. Chronic exposure is considered to produce only effects that can be observed some time following initial exposure.

2.2 Acute Exposure

Acute exposure is exposure to a large, single dose of radiation, or a series of doses, for a short period of time. Large acute doses can result from accidental or emergency exposures or from special medical procedures (radiation therapy).

3. Interaction of Radiation with Cells

Ionizing radiation affects people by depositing energy in body tissue, which can cause changes in the chemical balance of cell.

Radiation is thus seen to produce biological effect by two mechanisms, directly by dissociating molecules following their excitation and ionization; and indirectly by the production of free radicals and hydrogen peroxide in the water of the body fluids.

3-1 Direct Action

The complex molecules making up living organisms are composed of long strands of atoms forming proteins, carbohydrates and fats. They are held together by chemical bonds involving shared electrons. If the ionizing radiation displaces one of the electrons in a chemical bond, it can cause the chain of atoms to break apart, splitting the long molecule into fragments, or changing its shape by elongation. This is an ungluing of the complex chemical bonds so carefully structured to support and perpetuate life.

The gradual breakdown of these molecular bonds destroys the templates used by the body to make DNA and RNA (the information-carrying molecules in the cell) or causes abnormal cell division. The gradual natural breakdown of DNA and RNA is probably the cellular phenomenon associated with what we know as ageing. It occurs gradually over the years with exposure to natural background radiation from the radioactive substances which have been a part of the earth for all known ages.

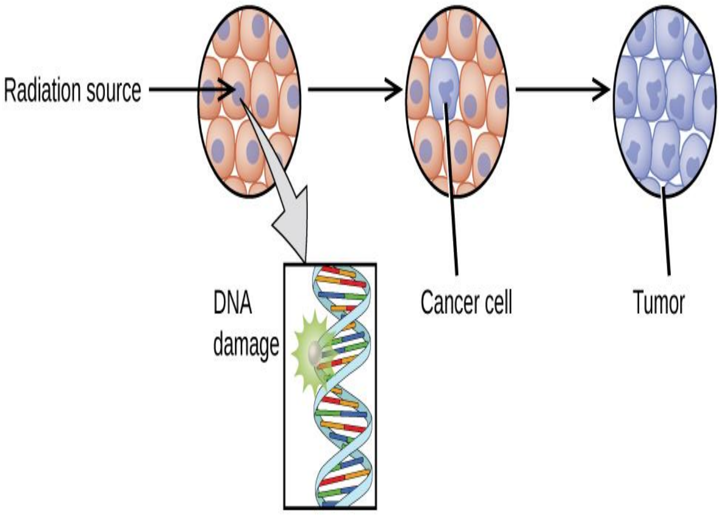

Figure 1: Direct action of ionizing radiation

3-2 Indirect Action

Most of the body is water, and most of the direct action of radiation therefore is in water. Ionization of water molecules cause them to split by a process called radiolysis

$$\textbf{Radiation} + H_2O = H_2O^+ + e^- \qquad \dots (1)$$

while the electron is picked up by the natural molecule

$$H_2O + e^- = H_2O^- \qquad \dots (2)$$

The net products of radiolysis of water molecules are the formation of highly reactive free radicals (a free radical is fragment of a compound or an element that contains an unpaired electron).

$$H_2O^+ = H^+ + OH^\cdot \qquad \dots (3)$$

$$H_2O^- = H^\cdot + OH^- \qquad \dots (4)$$

The ions H^+ and OH^- are of no consequence, since all body fluids already contain significant concentrations of both these ions. The free radicals $H^\cdot$ and $OH^\cdot$ may combine with like radicals to form gaseous hydrogen and hydrogen peroxide respectively.

$$H^{\cdot} + H^{\cdot} = H_2 \qquad \dots (5)$$

$$OH^{\cdot} + OH^{\cdot} = H_2O_2 \qquad \dots (6)$$

The hydrogen peroxide, being a relatively stable compound, persists long enough to diffuse to points quite remote from their point of origin. The hydrogen peroxide, which is a very powerful oxidizing agent, can thus affect molecules or cells that did not suffer radiation damage directly.

The hydrogen radical may combine with oxygen to form the hydroperoxyl radical which is not as reactive.

$$H^{\cdot} + O_2 = HO_2^{\cdot} \qquad \dots (7)$$

This greater stability allows the hydroperoxyl radical to combine with free hydrogen radical to form hydrogen peroxide, thereby further enhancing the toxicity of the radiation. The free radical $OH^{\cdot}$ may combine with nearby organic molecule R-H to form organic free radical ($R^{\cdot}$)

$$R\text{-}H + OH^{\cdot} = R^{\cdot} + H_2O \qquad \dots (8)$$

Organic free radical ($R^{\cdot}$) has high reactive ability to combine with other molecules in cell and inactivate it. Any two nearby organic radicals may decay, and then making an additional chemical links called cross links. These links will decrease the viscosity of the medium. By increasing these links the radiated medium gradually converts to gelatinous medium.

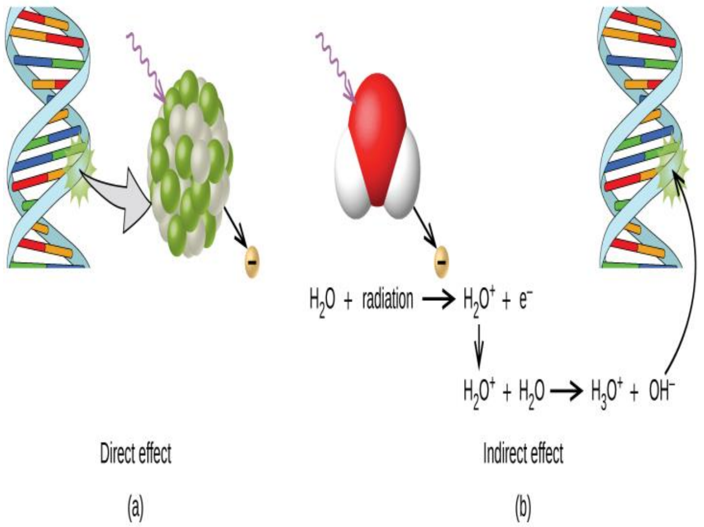

Figure 2: Indirect action of ionizing radiation

4- Biological Effects of Radiation

The biological effects of radiation divide into two groups: somatic effects, which affect the irradiated person and genetic or hereditary effects, which affect the descendants of the irradiated individual. Genetic effects are those related to the transmission of harmful hereditary information from one generation to the next. The effects are also divided into two categories in terms of the period between irradiation and appearance: short and long term effects.

4-1 Long-term Effects

Long-term effects may appear as a result of a chronic low-level exposure over a long period. These include genetic effects and other effects such as cancer, precancerous lesions, benign tumors, cataracts, skin changes, and congenital defects.

Evidence of injury from low or moderate doses of radiation may not show up for months or even years. For leukemia, the minimum time period between the radiation exposure and the appearance of disease (latency period) is 2 years. For solid tumors, the latency period is more than 5 years.

4-2 Short-term Effects

Short-term effects may appear as a result of an acute irradiation. These include both immediate and delayed effects. High levels of acute radiation exposure can result in death within a few hours, days or weeks.

An acute exposure, if large enough, it can cause different health effects depending on the amount and the time to onset of exposure as in table (1).

5- Radiation Induced Cancer

A long-term somatic effect is the damage of cells that is continually reproducing. These cells are the most sensitive to radiation because any changes made in the parent cell's chromosome structure will be transmitted to its daughters.

Table 1: Health effects due to different amounts of acute exposures

Equivalent dose (rem)	Health Effects	Time to Onset
5-10	changes in blood chemistry	hours
50	nausea	
55	fatigue	2-3 weeks
70	vomiting	
75	hair loss	
90	diarrhea	within 2 months
100	hemorrhage	
400	death from fatal doses	
1000	destruction of intestinal lining	1-2 weeks
	internal bleeding	
	death	
2000	damage to central nervous system	minutes
	loss of consciousness	
	death	hours to days

Also, radiation can affect the delicate chemistry of the cell causing changes in the rate of cell division or even the destruction of that cell. An event which causes a somatic cell to behave in this way is called a mutation.

The mutations in the reproductive cells translate the damage effects into future generations. However, a mutation in a somatic cell has consequences only for the individual. If the mutation in the somatic cell increases the rate of its reproduction in an uncontrolled manner, then the number of daughter cells may increase rapidly in that area. In this case, daughter cells are often divided before reaching their mature state. The result then is an ever increasing number of cells that have no beneficial function to the body, yet are absorbing body nutrition at an increasing rate. The tissue could now be called a tumor.

If the cells remain in their place of origin and do not directly invade surrounding tissues, the tumor is said to be benign. If the tumor invades neighboring tissue and causes distant secondary growths (called metastasis), it is known as malignant or cancer. Whether it is fatal or not depends on the tissue in which it is located, how rapidly it grows, and how soon it is detected.