Radiation Pollution Course (E-370)

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Chapter one (Environment)

1.1 Introduction

This course (Radiation Pollution) will focusing and discussing the sources of radiation pollution, types of radiation pollution, methods and devices (detectors) for radiation detection, units of radiation dose measurements, effects of radiation on environment and life, also the methods of prevention of radiation exposure and newly methods to reduce and remediate the radiation pollution will study as well. In addition, the methods for manage and immobilizing the radioactive waste (waste management) will study in this course.

1.2 The Environmental Definition

The environment includes the human and natural world and its surroundings, which consist of the atmosphere, hydrosphere and lithosphere. Human beings are very dependent on the environment. The atmosphere provides us with the air we breathe, the hydrosphere provides the water we drink, and the soil of the lithosphere provides us with the food that we eat. In addition, the environment provides us with raw materials to fulfill our other needs: the construction of housing; the production of consumer goods, etc. In a view of these important functions, it is imperative that we maintain the environment in a state that is as sustainable as possible. Fouling the environment by the entreated products of our industrial society (called pollution) may have many harmful consequences, the damage to human health being of greatest concern.

For that, environmental science is defined as a branch of science (Biology, Chemistry and Physics) focused on the study of the relationships of the natural world and the relationships between organisms and their environments.

At this current time, the world around us is changing at a very rapid pace. Some changes are beneficial, but many of the changes are causing damage to our planet. The field of environmental science is valuable resources for learning more about these changes and how they affect the world we live in. Let's examine a major change that is currently occurring and its relationship to environmental science. The large change is the dramatic increase in the number of humans on earth. For most of human history, the population has been less than a million people, but the current population has increased to over seven billion people. This equals out to seven thousand times more people.

Due to this increase in the human population, there has also been an increase in pressure on the natural resources and ecosystem services, which we depend on for survival. Natural resources include a variety of substances and energy sources that we take from the environment and use. Natural resources can be divided into renewable and nonrenewable resources. Renewable natural resources are substances that can be renewal over a period, such as sunlight, wind, soil, and wood. On the other hand, nonrenewable natural resources are substances that are in finite supply and will run out. Nonrenewable resources include minerals and crude oils. Then the increase in the human population, natural resources are being used up at a more rapid rate than in the past. Although renewable natural resources can be replenished, when they are used too rapidly, they cannot be replenished fast enough to meet human demand. Even worse, when nonrenewable natural resources are used too rapidly, they become closer to running out completely and being gone forever.

Natural resources have been referred to as the goods produced by the environment, and in this respect, ecosystem services are the 'facilities' that we depend on to help produce the goods. Ecosystem services are the environment's natural processes that provide us with the resources we need to support life. Common ecosystem services include water and air purification, nutrient cycling, climate regulation, pollination of plants, and the recycling of waste. Just like some natural resources, ecosystem services are also limited and can be used up if not regulated.

1.3 Environmental Pollution, it Sources and Effect

Environmental pollution has become a considerable problem threatening the life of people, animals and other living species. Thousands of waste sites around the world contain different pollutants and toxins, particularly heavy metals and radioactive elements. These sites pose a serious threat to all living organisms, and humans in particular. Environmental pollution can be defined as any discharge of material or energy into water, land and air, or can be due to introduction of contaminants into the natural environment that causes adverse changes, or may cause acute (short-term) or chronic (long-term) detriments to the Earth's ecological balance, or that lowers the quality of life. Pollutants may cause primary damage, with direct identifiable impacts on the environment, or secondary damage, in the form of minor perturbations in the delicate balance of the biological food web that are detectable only over long time periods

Environmental Pollution Sources

The industrialization of society and the explosion of the human population have changed the ecological system dramatically.

The random discharge of untreated industrial and domestic waste into waterways; the release of thousands of tons of particulates and airborne gases into the atmosphere;

The use of newly developed chemicals without considering potential consequences, have resulted in major environmental disasters, including the formation of smog and the pollution of large areas of the sea.

Introducing of chemical, physical or biological materials into fresh or seawater that degrading the quality of the water and affect the organisms living in it.

The most dangerous type of pollution is radioactive contamination that results from the detonation of nuclear devices and other nuclear fallout. Nuclear fallout typically occurs from leaks from nuclear power plants, and from conventional weapons using depleted uranium.

Nuclear explosion create radioactive dust and ash, consisting of materials either directly vaporized by a nuclear blast or charged by exposure, a highly dangerous radioactive contamination. It can lead to contamination of the environment and has a devastating effect on ecosystems years after the initial exposure.

Other sources of radiation include spent fuel from nuclear plants, and by-products of mining operations and experimental research laboratories.

Environmental Pollution Effect

Pollution effects are indeed many and wide-ranging, high levels of pollution may causing a lot of damage to human & animal health, trees (tropical rainforests), as well as the wider environment,

All types of pollution (radiation pollution, heavy metals and toxins) have an impact on the living environment,

The effects in living organisms may range from mild discomfort to serious diseases such as cancer and genetic mutation (congenital malformation or physical deformities).

The effect of pollution on human maybe causes:-

- Reduced lung functioning
- Irritation of eyes, nose, mouth and throat
- Asthma attacks
- Respiratory symptoms such as coughing
- Increased respiratory disease
- Reduced energy levels
- Headaches and dizziness
- Cardiovascular problems
- Cancer
- Premature death
- genetic mutation (congenital malformation)
- Damage to the nervous system
- Liver and kidney damage
- Damage to the DNA

The effect of pollution on animals and plant maybe causes:-

- Acid rain destroys fish life in lakes and streams (rivers)
- Excessive ultraviolet radiation coming from the sun through the ozone layer in the upper atmosphere which is eroded by some air pollutants, may cause skin cancer in wildlife
- Ozone in the lower atmosphere may damage lung tissues of animals
- Nutrient pollution (nitrogen, phosphates etc) causes overgrowth of toxic algae eaten by other aquatic animals, and may cause death; nutrient pollution can also cause outbreaks of fish diseases
- Oil pollution (as part of chemical contamination) can negatively affect development of marine organisms, can also cause liver damage, kidney damage, and damage to the nervous system
- Acid rain can kill trees, destroy the leaves of plants
- Ozone holes in the upper atmosphere can allow ultraviolet radiation from the sun to enter the Earth causing damage to trees and plants
- Ozone in the lower atmosphere can prevent plant respiration by blocking stomata (openings in leaves) and negatively affecting plants' photosynthesis rates which will stunt plant growth
- The radiation pollution effects vary depending on the amount of radiation to which we are exposed and on the sensitivity of each exposed individual. Thus, while exposure to high amounts of radiation almost always generate serious diseases (cancer)
- Cancer due to radiation exposure at lower doses usually develops years after the actual exposure; lung cancer is a typical example of the effect of exposure to radon (Helium Nuclide).

1.4 Type of Pollution (Pollutants)

There are many types of environmental pollutants, this is including

1. Radiation Pollution

Radiation occurs naturally in the environment; Natural radiation exists everywhere around the Earth in different levels, but radiation pollution is the most dangerous type of pollutions.

2. Heavy Metals Pollution (Sold, Liquid, Gas)

Heavy metal pollution (in each state) is a problem associated with areas of intensive industry. However, roadways and automobiles are now considering as one of the largest sources of heavy metal pollution.

3. Toxins (Sold, Liquid, Gas)

Toxic and non-biodegradable pollutants released into the environment by industrial, mining and agricultural activities.

Exercise 1:

Classify the Uranium Isotopes, what is the different between them and their properties.

Exercise 2:

What are the ozone holes, how it is exists at the atmosphere layers and do have any idea in order to sort this problem.

Chapter Two (Radiation)

Radiation occurs naturally in the environment that called background radiation; therefore, radionuclide is of naturally present in air, water, soil, sediments, wood, rocks, building materials, and food. Natural radiation exists everywhere around the Earth in different levels. This means radiation can found all around us. Our natural environment, the food we eat, the water we drink, and the air we breathe may contain or being affected by some radioactive materials.

Radioactive contamination is a result of spreading radioactive isotopes during the nuclear tests, nuclear explosion, nuclear wastes and depleted Uranium.

2.1 Type of Radiation

The four major types of radiation are:

- Gamma (γ) radiation - high-energy electromagnetic waves;
- Beta (β) radiation - emission of electrons or positrons;
- Alfa (α) radiation - emission of Helium nucleus (He_2^4);
- Neutron radiation - emission of high or low energy neutrons;

Gamma Rays

A gamma ray is a packet of high-energy electromagnetic waves (or photons). Gamma photons are the most energetic in the electromagnetic spectrum, emitting from the nucleus of some unstable (radioactive) nucleus. Gamma photon have no rest mass, no electrical charge, they are pure electromagnetic energy. High energy gamma photons travel at the speed of light in vacuum and can cover hundreds of meters in the air before dispersing their energy, They can easily pass through different types of materials, including human tissue, so both external and internal exposure to gamma rays have to be considered.

Gamma radiation has enough energy to pass entirely through the human body, potentially exposing all internal organs. High-energy gamma radiation, having a very small cross-section of interaction, passes through the human body practically without interacting with tissue.

The speed of gamma photons (C) is independent of their wavelength, frequency, and energy, and it is the same as that of all other types of electromagnetic radiation ($C=3.10^8$ m/sec in vacuum). Their wavelength (λ), frequency (ν) and energy (E) are correlated by the following equations

$$\lambda = \frac{C}{v} \, , \qquad E = hv \qquad (2.1)$$

Where h is the blank constant, (define h).

Unstable nuclide move from higher energy state to a lower energy state by emitting a gamma ray, gamma radiation also can be produce by other forms of radiation, such as alpha or beta, through the secondary nuclear reactions (decays). The mechanism involves a nucleus emitting α or β particles, and the daughter nucleus can also be in an excited state. Emission of gamma rays from an excited nuclear state typically requires only 10^{-12} seconds, followed by another radioactive decay that produces other radioactive particles.

For example, ^{60}Co decays to an excited ^{60}Ni by beta decay. Then the ^{60}Ni drops down to the ground state by emitting two gamma rays in sequence (1.17 MeV then 1.33 MeV), as shown in Figure 2.1.

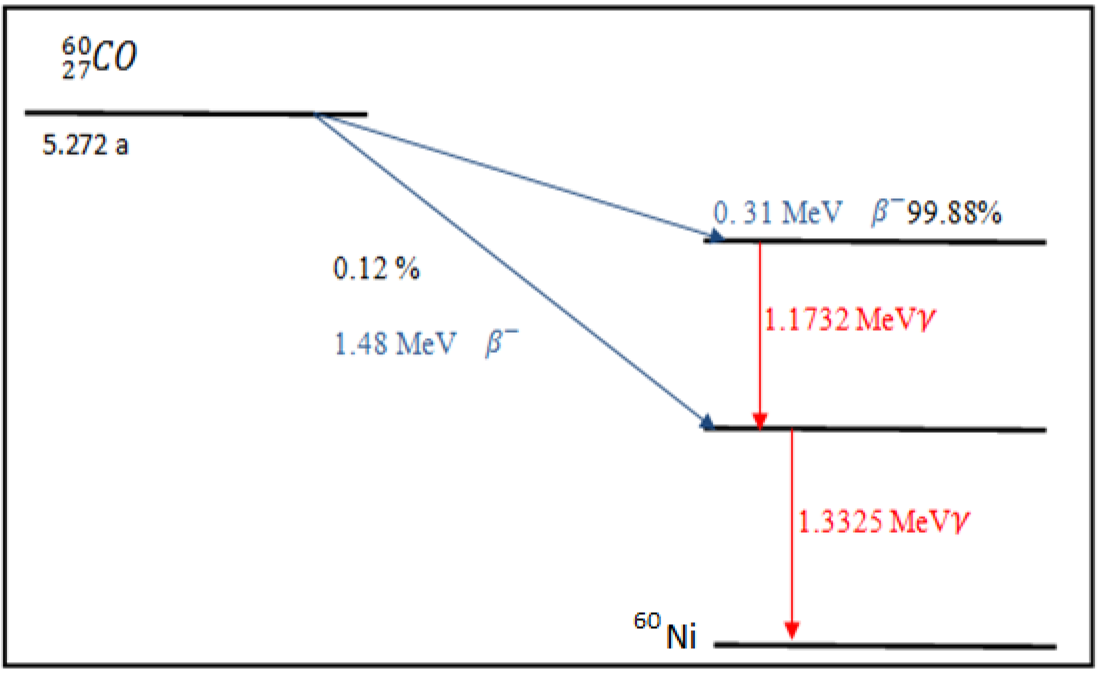


Figure 2.1. The scheme of decay of ^{60}CO to ^{60}Ni

Beta particles (β)

Beta particles (β) are subatomic particles ejected from the nucleus of some radioactive atoms, equivalent to electrons. The difference is that beta particles originate in the nucleus and electrons originate outside the nucleus. Beta particles have an electrical charge of (1e). Beta particles have a mass of 549 millionth of one atomic mass unit, which is about 1/2000 of the mass of a proton or neutron. The speed of individual beta particles depends on how much energy they have.

Direct exposure to beta particles is a relatively small hazard; it may cause skin to redden or even burn. The beta-emission from inhaled or ingested substances, however, is the greatest concern. Beta particles released directly into living tissue can cause damage at the molecular level, which can disrupt cell function.

Beta particles do not exist in the unstable nucleus before emission, they are produced from sub-nuclear transformation, whereby a neutron changes to a proton, (β- particle is emitted) thus:

$$n \rightarrow p + e^{-} + v^{-} \qquad (2.2)$$

Alternatively, a proton changes to a neutron (a β+ particle is emitted):

$$p \rightarrow n + e^{+} + v \qquad (2.3)$$

Whereas a neutrons outside a nucleus undergoes negative beta decay and transforms into proton with a half-decay time (t½ =12 min. 16 sec.), much lighter protons cannot be transformed into a neutron except within a nucleus. **(Define; Neutrino, Deuterium)**

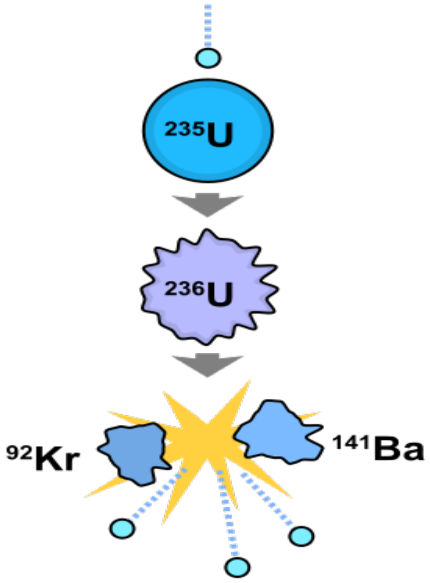
Alpha particles (α)

An alpha particle consists of two protons and two neutrons bound together into a particle identical to a helium nucleus. They are generally produced in the process of alpha decay, but may also be made by other means. The symbol for the alpha particle is α or α^{2+}. Because they are identical to the helium nuclei, they are also sometimes written as $^{4}_{2}He^{2+}$, indicating a Helium ion with a +2 charge (missing its two electrons). If the ion gains electrons from its environment, the alpha particle can be written as a normal (electrically neutral) Helium atom. The most well known source of alpha particles is alpha decay of large atoms heavier than 106 units of atomic weight.

When an atom emits an alpha particle, the atom's mass number decreases by four, due to the loss of the four nucleons in the alpha particle, so the atomic number of the atom goes down by exactly two, because of the loss of two protons, the atom becomes a new element. All of the larger radioactive nuclei, such as Uranium, Thorium, Actinium, and Radium commonly emit alpha particles. Unlike other types of decay, alpha decay must have a minimum size atomic nucleus that can support it. The smallest nuclei that have to date been found to be capable of alpha emission are the lightest nuclides of Tellurium (element 52), with a mass numbers between 106 and 110. The process of alpha-emission sometimes leaves the nucleus in an excited state, with the emission of a gamma ray required in order to remove the excess energy.

Neutron radiation

Neutron radiation is a kind of ionizing radiation that consists of free neutrons. As a result of nuclear fission, free neutrons are released from atoms, and these free neutrons react with the nuclei of other atoms to form new isotopes which may produce radiation (In nuclear physics, nuclear fission is either a nuclear reaction or a radioactive decay process in which the nucleus of an atom splits into smaller parts (lighter nuclei). The fission process often produces free neutrons and photons (in the form of gamma rays), and releases a very large amount of energy even by the energetic standards of radioactive decay).



An induced fission reaction. A neutron is absorbed by a uranium-235 nucleus, turning it briefly into an excited uranium-236 nucleus, with the excitation energy provided by the kinetic energy of the neutron plus the forces that bind the neutron. The uranium-236, in turn, splits into fast-moving lighter elements (fission products) and releases three free neutrons. At the same time, one or more "prompt gamma rays" (not shown) are produced, as well.

Neutrons may be emitting from nuclear fusion or nuclear fission, or from other types of nuclear reactions, such as radioactive decay or reactions with highly energetic particles, either coming as cosmic rays or created in particle accelerators

Neutron radiation was discovered through observing a Beryllium (atomic No. 4) nucleus reacting with an alpha particle, thus transforming into a Carbon (atomic No. 6) nucleus and emitting a neutron. ($Be + \alpha \rightarrow C + n$).

2.2 Radiation Sources (Natural and Artificial)

Radioactive contaminants are typically unstable radionuclide (or radioisotopes), some of them naturally occurring in the environment, such as Potassium-40 (^{40}K) and Radium-226, while others, such as Strontium-90 (^{90}Sr) and Technetium-99 (^{99}Tc), appear as a result of human activities.

The presence of several natural radionuclide such as Tritium (^{3}H) and particularly Uranium-238 (^{238}U) has been substantially enhanced in the last 5-6 decades due to various nuclear projects of either military of civil origin.

The radiation is constantly present in the natural environment and called background radiation. It can be caused by numerous sources, including the following: Cosmic rays, the effect of which strongly depends on the state of stratosphere (e.g., “ozone holes” have recently appeared);

1-Radon gas, released from the Earth's crust into the atmosphere and then attaching to airborne dust and other particulate (granular, powder) materials, that human beings might ingest and inhale;

2-Radionuclide’s, present in natural minerals, stones and therefore in building materials;

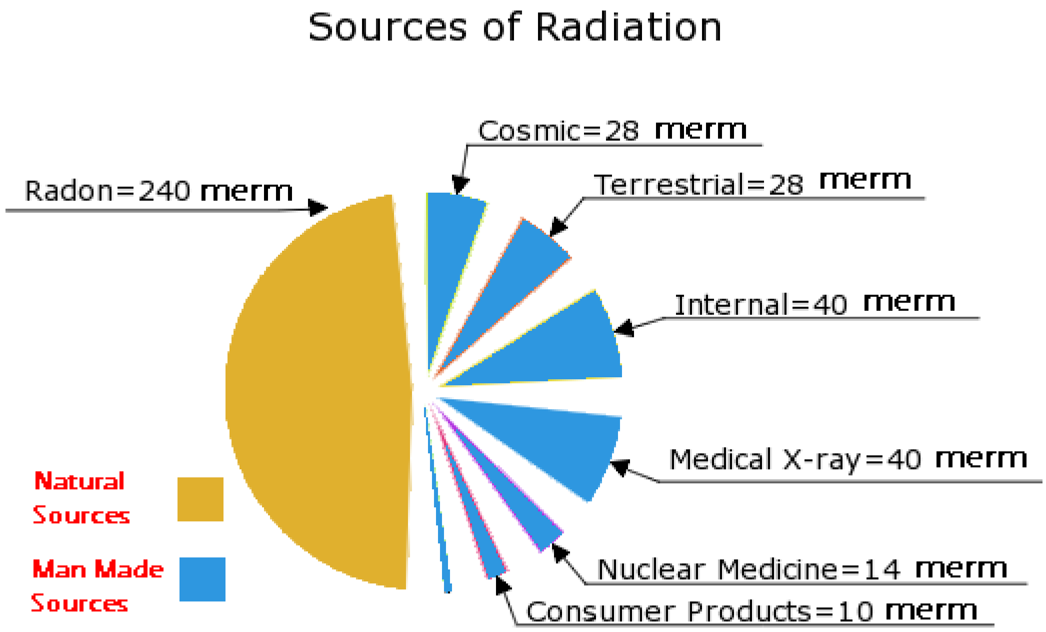
3-Mineral hot springs, containing mostly Radium 226 and small amounts of other radioisotopes that are rather useful and used by people as spas.

4-Artificial sources of background radiation used in radiological imaging and radiation therapy cannot be excluded from this list.

Average annual human exposure to ionizing radiation in millisievert (mSv)

Radiation source	World			Remark
Inhalation of air	1.26			mainly from radon, depends on indoor accumulation
Ingestion of food & water	0.29			(K-40, C-14, etc.)
Terrestrial radiation from ground	0.48			depends on soil and building material
Cosmic radiation from space	0.39			depends on altitude
subtotal (natural)	2.40			sizeable population groups receive 10-20 mSv
Medical	0.60			World-wide figure excludes radiotherapy; mostly CT scans and nuclear medicine.
Consumer items	-			cigarettes, air travel, building materials, etc.
Atmospheric nuclear testing	0.005			peak of 0.11 mSv in 1963 and declining since; higher near sites

Occupational exposure	0.005			Worldwide average to all workers is 0.7 mSv, mostly due to radon in mines also the medical and aviation workers.
Chernobyl accident	0.002			peak of 0.04 mSv in 1986 and declining since; higher near site
Nuclear fuel cycle	0.0002			up to 0.02 mSv near sites; excludes occupational exposure
Other	-			Industrial, security, medical, educational, and research
subtotal (artificial)	0.61			
Total	3.01			**millisievert per year**



2.3 Radiation Dose and Units

Exposure is a measure of ionization produced in air by X- rays or gamma rays passing through a mass (*m*) of dry air at standard temperature 0 °C and pressure of 1 atm. When passing through the air, the beam produces positive ions whose total charge is *q*. Exposure is defined as the total charge per unit mass of air.

$$Exposure\ (X) = q/m$$

The SI unit for exposure is Coulombs per kilogram (C/kg). However, the first radiation unit to be defined was the Roentgen (R), with *q* expressed in Coulombs and *m* in kilograms (kg). The exposure in Roentgen is given by

$$X(R) = 2.5 * 10^{-4} q/m$$

Thus, when X-rays or γ-rays produce an exposure of one Roentgen, a positive charge of $2.5\text{x}10^{-4}$C is produced in 1kg of dry air, and one roentgen equal:-

$$1\text{R} = 2.5 * 10^{-4} C/Kg$$

For biological purposes, the absorbed dose is a more suitable quantity, because it is the energy absorbed from radiation per unit mass of absorbing material.

Absorbed dose = (Energy absorbed) / (Mass of absorbing material)

The SI unit of absorbed dose is Gray (Gy), which is a unit of energy divided by a unit of mass: Gy =J/kg. Another unit often used for absorbed dose is rad (rd), an acronym for ‘radiation absorbed dose’. The rad and Gray are related by 1rad = 0.01Gray.

Rad is the amount of energy, which the human body absorbs. However, equal doses of different types of radiation may not have the same effects on the body; for instance, a dose of alpha particles is more damaging than the same dose of gamma rays or beta particles. To compare the damage caused by different types of radiation, relative biological effectiveness (RBE) is used, also called the quality factor (QF). The relative biological effectiveness of particular type of radiation compares the dose of that radiation needed to produce a certain biological effect, to the X- rays needed to produce the same biological effect.

RBE= [the dose that produces a certain (reference) biological effect /the dose of X-rays radiation that produces same biological effect].

The RBE depends on the ionizing radiation and its energy, as well as the type of tissue being irradiated.

Type of radiation	**RBE**
200-keV X-rays	1
X- rays	1
β-particles (electrons)	1-2
Protons	10
α- particles	10-20
slow neutrons	2
fast neutrons	10

Table. 2.1. Typical RBE values for different kinds of radiation.

The RBE is often used in connection with the absorbed dose to reflect the character of damage produced by radiation. The product of the absorbed dose in rad and RBE is the biologically equivalent dose (DE).

Biologically equivalent dose (in rem) =Absorbed dose in (rad) * RBE

$$DE=D*RBE$$

The unit for the biologically equivalent dose is the rem. The rem is the unit of radiation, which accounts for the different effects of different types of radiation. In order to calculate the equivalent dose in rem, the absorbed dose must be established. The unit of DE is Sievert if the unit of the absorbed dose (D) is Gray, or if the unit of the absorbed dose (D) is rad, then the unit of DE is rem.

Where: 1Sievert =100 rem.

2.4 Effect of radiation on Environment and Life

The effect of radiation on living organisms, including humans, appears mostly at cell level, since ionizing radiation can potentially affect the normal operation of cells. The biological effect of radiation lies in the ionization of atoms and molecules in the tissue.

Ionizing radiation absorbed by human tissue has sufficient energy for ionization of atoms; this may subsequently lead to breaking chemical bonds and thus molecules. This is a basic model for understanding radiation damage. For a deeper understanding of the effect of ionizing radiation on cells, one needs to consider damage to critical parts of the cell, such as chromosomes that contain genetic information and instructions required for the cell to function, as well as to make copies of it for reproduction purposes. On the other hand, the cells have very

effective repair mechanisms, which operate permanently and repair cellular damage - including chromosome damage.
Ionization may form chemically active substances that in some cases alter the structure of the cells. These alterations may be similar to those changes that occur naturally in the cell and may have no negative effect. Some ionizing events produce substances (such as amino acids or enzymes) not normally found in the cell. These can lead to a breakdown of the cell structure and its components. Cells can repair the damage if it is limited. Even damage to chromosomes is usually repairable; thousands of chromosome aberrations occur constantly in our bodies and the majorities are repaired spontaneously.

If a damaged cell needs to perform a function but does not have sufficient time to repair itself, it will be either unable to perform the repair function or perform the repair function incorrectly (incompletely). This could be damaging to other cells. These altered cells may become unable to reproduce themselves or may reproduce at an uncontrolled rate. Such cells can be the underlying causes of cancers. The cell may die if a cell is broadly damaged by radiation or if the damaged in such a way that the reproduction is affected.

Radiation damage to cells may depend on the sensitivity of these cells to radiation. Not all cells are equally sensitive to radiation damage. In general, cells that divide rapidly and/or are relatively non-specialized tend to show effects at lower doses of radiation then those which divide less rapidly and are more specialized. Examples of such radiation sensitive cells are those involved in the production of blood, this system (called the hematopoietic system) is the most sensitive biological indicator of radiation exposure. Radiation doses can be grouped into two categories: *acute* and *chronic*. An acute radiation dose is defined as a large dose (10 rad or greater to the whole body) delivered during a short period (about a few days at most). If the dose is large enough, the negative effects may appear within a short period (hours, days, or weeks). Acute doses can cause a pattern of clearly identifiable symptoms (syndromes). These conditions are referred to as Acute Radiation Syndrome. Symptoms of radiation sickness are apparent following the acute doses of more than 100 rad. acute doses of more than 450 rad may result in a statistical expectation of 50% of the exposed population to die within 60 days, without medical attention. As in most illnesses, the specific symptoms, the therapy that a doctor might prescribe, and the prospects for recovery vary from one person to another and are generally dependent on the age and general health of the individual.

The syndrome of bone marrow (blood-forming organ) which normally appears at doses higher than 100 rad is characterized by damage to cells that divide at the most rapid pace (such as bone marrow, the spleen, and lymphatic tissue). Symptoms include internal bleeding, fatigue, bacterial infections, and fever.

Central nervous system syndrome at doses higher than 5000 rad is associated with the damage of nerve cells that are not reproducible. Symptoms include loss of coordination, confusion, coma, convulsions, shock, etc.

Other effects from an acute dose include 200 to 300 rad to the skin can result in the reddening of the skin. Similar to mild sunburn, and may result in hair loss due to damage to hair follicles; 600 rad to the ovaries or testicles can result in permanent sterility; and 50 rad to the thyroid gland can result in non-cancerous tumours. The effects caused by acute doses are called deterministic.

Humans and other organisms are continuously exposed to ionizing radiation from natural background sources in the environment, including cosmic radiation and Rn-222, alongside K-40 and C-14. This unavoidable exposure is not without consequences, as ionizing radiation exposure has been known to deliver a variety of injuries to DNA. Unfortunately, natural background is not the only source of ionizing radiation to which organisms are exposed. Numerous sites around the world have been contaminated with radionuclide, because of anthropogenic activity. Human exposure can be minimized by limiting access to contaminated areas, but this is generally not feasible for other species, and resulting exposures can be significantly higher than those from natural background sources. In general, radiation exposure may be internal or external. Internal exposure comes from eating or drinking contaminated food or water, or from breathing contaminated air. A radioactive substance can also enter the body through cuts in the skin. Alpha- and beta- radiations contribute to internal exposure. External exposure can come from beta, gamma and X- ray; both internal and external radiation exposure can directly harm cells. When the body is exposed to radiation, the following events on the cell-level may occur:-

1- Radiation may pass through the cell without detectable damage.
2- It may damage the cell, but the cell may be able to repair the damage before producing new cells.
3- It may damage the cell in such a way that damage is passed on when new cells are formed.
4- It may kill the cell.

If the radiation passes through the cell without causing damage or the cell repairs itself successfully (number 1 and 2 above), there is no lasting damage or health effect. If the damage is passed on when new cells are formed (number 3 above), there may be a delayed health effect, such as genetic effects. When radiation kills a cell, there will be an acute (immediate) health effect if the dose is high and many cells die. Death may occur within days or weeks from the moment of exposure to radiation.

Ionizing radiation acting on living system can result in biological endpoints, including tissue injury, carcinogenesis and death. The initial step in this interaction of radiation with biological material is the deposition of energy into atoms and molecules that results in ionization and excitation. Small quantities of energy from radiation exposure result from the non-uniform deposition of energy and through biochemical processes that amplify damage.

There are two actions of ionization radiation on cell. Firstly, the direct action, when a molecule is ionized and/or excited by the incident of radiation, as has already been stated, the extra portion of energy of the ionizing particle is used to remove an electron from a molecule. The remaining energy excites the molecule and can actually break molecules into smaller units that are identical because many larger molecules are composed of a chain of smaller molecules bonded together chemically. It appears that damage occurs at the same bond.

Direct action occurs within milliseconds of irradiation. This type of action causes a number of physical events that bring about the death of the cell.

The radiation risk level depends on several factors, namely 1. The type of radioactive isotopes; 2. The radiation intensity and exposure period. Living organisms are affected differently by high or low levels of radiation sources; while, 3. The period of exposure also has a crucial effect on living cells. The effect of a low level of radiation (particularly with long time exposure) causes changes in DNA structure, which can result in different types of cancer and/or genetic transformations, called indirect action.

Free radicals result from radiation exposure; these are electrically neutral, having an unpaired electron in there outer orbits. Free radicals are formed by radiation when an atom is left with one of its outer orbital electrons unpaired with respect to spin. Free radicals are usually very reactive since they have a great tendency to pair the odd electron with a similar one in another free radical or to eliminate the odd electron by an electron transfer reaction. Free radicals can therefore be electron acceptors (oxidizing species) or electron donors (reducing species).

The simplest free radical is the hydrogen atom, which contains one proton and one electron. The most important radicals that may be involved in disease processes are species that maybe derived from molecular oxygen, and certain oxides of nitrogen, especially nitric oxide. An unpaired electron can be associated with almost any atom, but oxygen and carbon-centered free radicals are of the greatest biological relevance.

Sources of radicals are alcohol, cigarette smoking, stress, strain, anger, air pollution, and solar radiation.

Radioactive decay

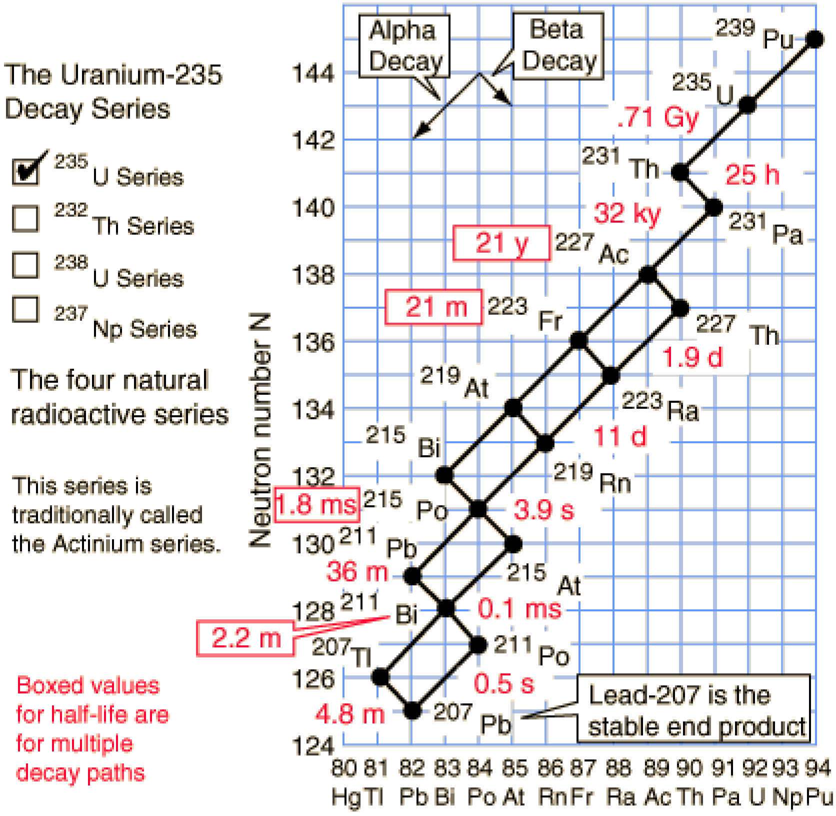
Radioactive decay, also known as nuclear decay or radioactivity, is the process by which the nucleus of an unstable atom loses energy by emitting radiation, including alpha particles, beta particles, gamma rays and conversion electrons. A material that spontaneously emits such radiation is considered radioactive.

Radioactive decay is a stochastic (i.e. random) process at the level of single atoms, in that, according to quantum theory, it is impossible to predict when a particular atom will decay. The chance that a given atom will decay never changes, that is, it does not matter how long the atom has existed. The decay rate for a large collection of atoms, however, can be calculated from their measured decay constants or half-lives.

There are many different types of radioactive decay (see table below). A decay, or loss of energy from the nucleus, results when an atom with one type of nucleus, called the parent radionuclide (or parent radioisotope, transforms into an atom with a nucleus in a different state, or with a nucleus containing a different number of protons and neutrons. The product is called the daughter nuclide. In some decays, the parent and the daughter nuclides are different chemical elements, and thus the decay process results in the creation of an atom of a different element. This is known as a nuclear transmutation.

Decay chain

The decay chain refers to the radioactive decay of different discrete radioactive decay products as a chained series of transformations. They are also known as "radioactive cascades". Most radioisotopes do not decay directly to a stable state, but rather undergo a series of decays until eventually a stable isotope is reached.

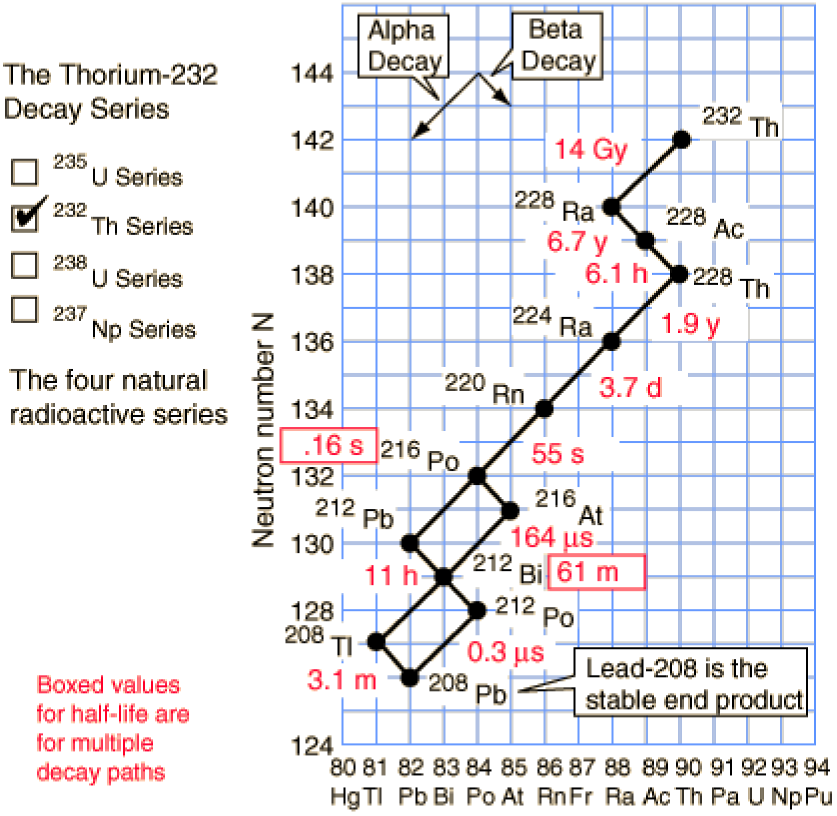

The Uranium-235 Decay Series

☑ ^{235}U Series
☐ ^{232}Th Series
☐ ^{238}U Series
☐ ^{237}Np Series

The four natural radioactive series

This series is traditionally called the Actinium series.

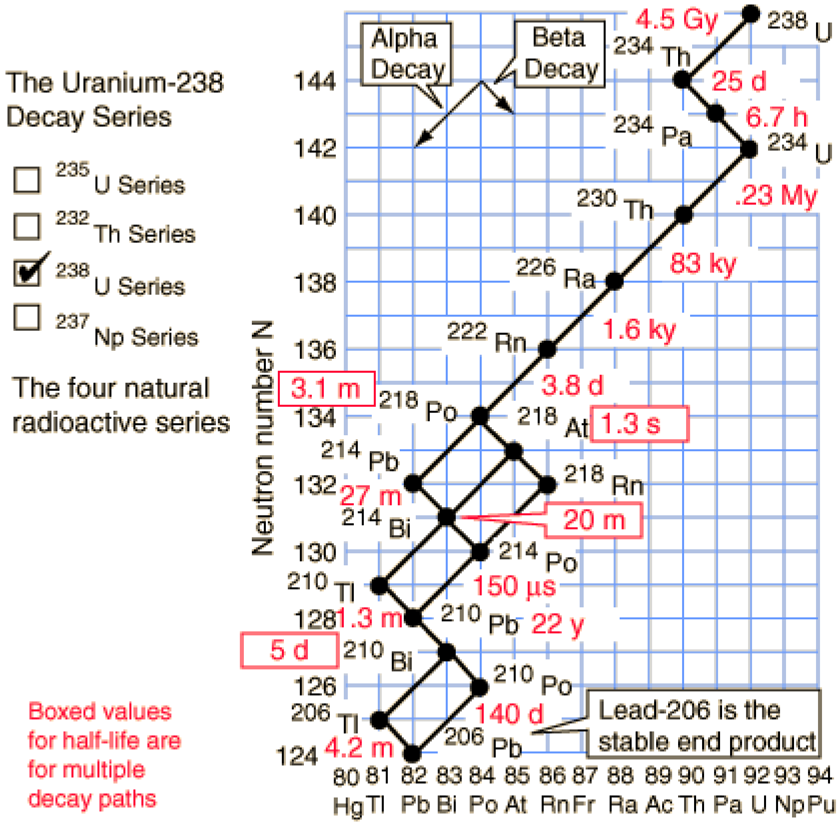
Boxed values for half-life are for multiple decay paths

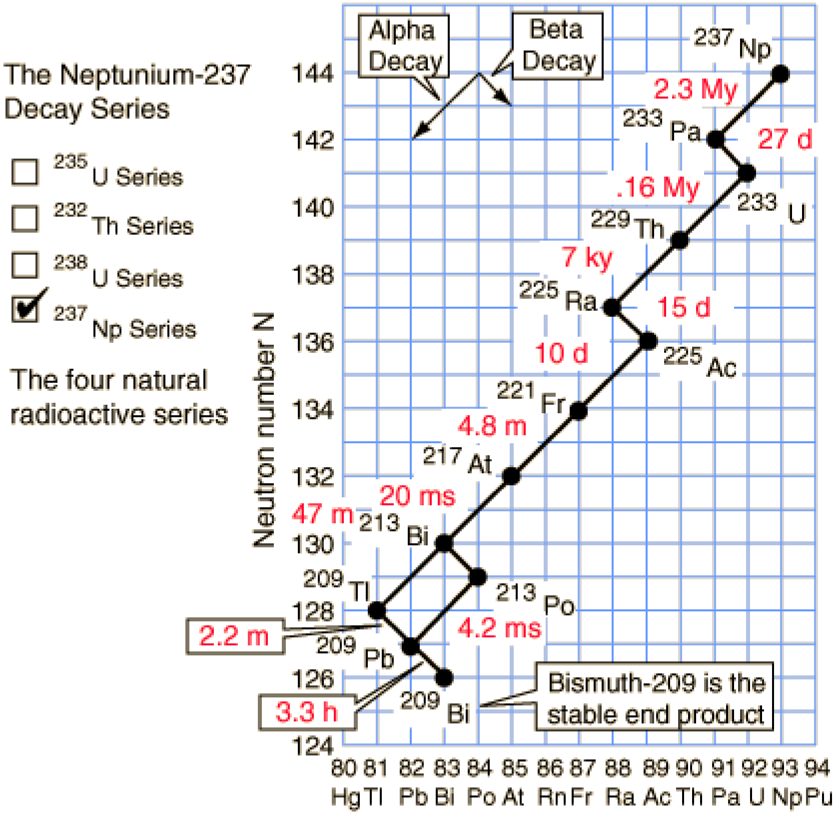

The Thorium-232 Decay Series

☐ ^{235}U Series
☑ ^{232}Th Series
☐ ^{238}U Series
☐ ^{237}Np Series

The four natural radioactive series

Boxed values for half-life are for multiple decay paths


The Uranium-238 Decay Series
☐ 235 U Series
☐ 232 Th Series
☑ 238 U Series
☐ 237 Np Series
The four natural radioactive series
Boxed values for half-life are for multiple decay paths
Alpha Decay
Beta Decay
Neutron number N
144
142
140
138
136
134
132
130
128
126
124
238 U
4.5 Gy
234 Th
25 d
6.7 h
234 Pa
234 U
.23 My
230 Th
83 ky
226 Ra
1.6 ky
222 Rn
3.8 d
218 Po
3.1 m
218 At
1.3 s
214 Pb
218 Rn
27 m
214 Bi
20 m
214 Po
150 µs
210 Tl
1.3 m
210 Pb
22 y
5 d
210 Bi
210 Po
140 d
206 Tl
4.2 m
206 Pb
Lead-206 is the stable end product
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94
Hg Tl Pb Bi Po At Rn Fr Ra Ac Th Pa U Np Pu


The Neptunium-237 Decay Series
☐ 235 U Series
☐ 232 Th Series
☐ 238 U Series
☑ 237 Np Series
The four natural radioactive series
Alpha Decay
Beta Decay
Neutron number N
144
142
140
138
136
134
132
130
128
126
124
237 Np
2.3 My
233 Pa
27 d
233 U
.16 My
229 Th
7 ky
225 Ra
15 d
225 Ac
10 d
221 Fr
4.8 m
217 At
20 ms
47 m
213 Bi
209 Tl
213 Po
2.2 m
4.2 ms
209 Pb
3.3 h
209 Bi
Bismuth-209 is the stable end product
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94
Hg Tl Pb Bi Po At Rn Fr Ra Ac Th Pa U Np Pu

Chapter Three (Detection of Radiation)

3.1 Indicators of Radiation Pollution

Radiation pollution levels can be measured directly. The presence or absence of certain living organisms can also act as an indicator of the amount of radiation pollution.

Plants consider are efficient, cheap and natural available monitor systems or bioassays for level of radiation pollution. The type and concentration of pollutants can be reliably found out by various characteristics damage symptoms produced in the plants because such damage symptoms are pollutant specific as well as concentration specific.

The accumulation of radionuclide by plants acting as a monitoring system in the environment may occur by two modes; foliar absorption by the leaves and shoot of the plant, or by root uptake from the soil. Data on plant accumulation of radionuclide's may be obtained from studies of fission product radionuclides deposited as worldwide fallout, and from tracer studies of plant physiology.

The role of plants as monitors of radionuclides is twofold: as monitors of recent atmospheric releases of radionuclides; and as indicators of the long-term behavior of aged deposits of radionuclides in the soil.

Also the animal species, which can be used as biological indicators of radionuclide contamination.

The pollen-bee-honey using to study movement of radioactive elements in the plant-animal-man food chain. Pollen, bees, and honey are collecting from different locations at a nuclear facility. The pollen is a more sensitive indicator of pollution than bees or honey. If pollen monitoring shows that, an area has become polluted.

The effects of radiation doses on organisms differ from specie to others, so that the effects of radiation on microorganisms are utilizing to detect and assay the radiation level. Some of species are sensitive to radiation pollution, for that it’s using to detect the radiation at low level, on the other hand, some of species can resist the radiation, then it’s using to determine the radiation at intermediate and high level.

3.2 Method of Detection

To tackle the problem of environmental pollution, the reliable methods of detection and identification of pollutants must be research. In the last 40-50 years, a large number of analytical methods for the detection of radioactive contamination have been developed. For example, different types of penetrative radiation (α, β, γ, or neutron) can be detected using physical, chemical and biological methods,

Belong of the biological method; there are many organs and microorganisms being using as indicators for radionuclide contaminations, for example the blood, skin tissue and the bacteria or DNA as microorganisms technique. The E. coli bacteria response for ionizing radiation been using as bioassay at low level of radiation pollution. In contrast, the Dinaccocas Radiodurans bacteria were utilizing for detect the radiation pollution at intermediate and high level of pollution.

Chemical methods focus on the analysis of sample for their radionuclide content. Various methods are employed to purify and identify the radioelement of interest through chemical methods and sample measurement techniques.

Physical method employing various techniques and devices for this purpose, there are a large numbers of detectors are using for radiation detection.

3.3 Detectors and Measurements

Radiation cannot be detected by human senses. A variety of handheld and laboratory instruments is available for detecting and measuring radiation. The most common handheld or portable instruments are:

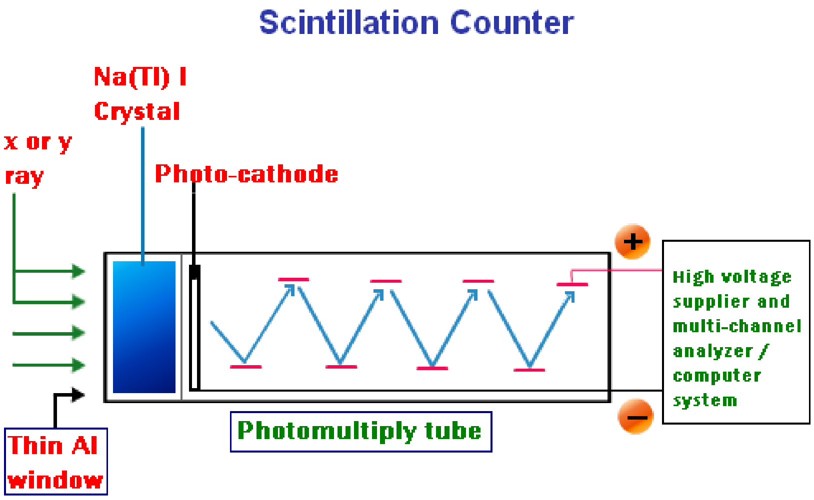
3.3.1 Scintillation counters

A scintillation counter is an instrument for detecting and measuring ionizing radiation by using the excitation effect of incident radiation on a scintillator material (NaI), and detecting the resultant light pulses.

It consists of a scintillator that generates photons in response to incident radiation, a sensitive photomultiplier tube that converts the light to an electrical signal and electronics to process this signal.

Scintillation counters are widely used in radiation protection, assay of radioactive materials and physics research because they can be made inexpensively yet with good quantum efficiency, and can measure both the intensity and the energy of incident radiation.

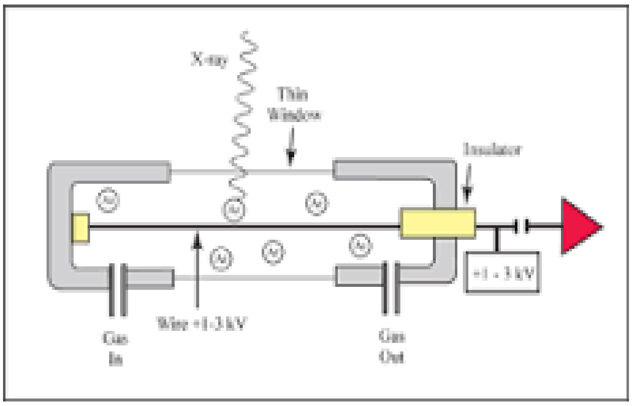
When the radiation interacts with certain materials flashes of light can be seen, the phenomenon called ‘scintillation”. Detection of these flashes either by the naked eye or with the help of optical instrumentation was one of the oldest methods of radiation detection. Rutherford used a ZnS scintillating screen, and employed this method to count the scattered alpha particles in the historic alpha-scattering experiment. This method is tedious and very crude and was soon replaced by gas counters, where the counting is done electronically and additional information about the energy of radiation can be obtained if needed. In 1944, Curran and Baker started using a photomultiplier in scintillating chambers, and later Kallman replaced ZnS crystals with naphthalene. These two changes revolutionized scintillation detection, making it possible to electronically detect, record, and analyze pulses produced by radiation.



Scintillation Counter Diagram

3.3.2 Gas counters

Geiger from Rutherford's laboratory developed gas counters for the detection of radiation in 1908. These counters became practical for the measurement of radiation shortly thereafter, even though scintillates were for a long time in use for this purpose. The original Geiger counter consists of a glass cylinder (containing idle or rare gas), an outer cylindrical electrode and an inner wire electrode, with a potential difference applied between them. Geiger found that radiation causes the ionization of gas and therefore an electric current between electrodes, which was detectable with an electrometer of “moderate sensibility”. The amount of charge (current) depends on the amount of radiation energy penetrating the gas tube.



Gas detector diagram

The Geiger-Müller tube is filled with an inert gas such as helium, neon, or argon at low pressure, to which a high voltage is applied. The tube briefly conducts electrical charge when a particle or photon of incident radiation makes the gas conductive by ionization. The ionization is considerably amplified within the tube by the Townsend Discharge effect (The Townsend discharge or Townsend avalanche is a gas ionisation process where free electrons are accelerated by an electric field, collide with gas molecules, and consequently free additional electrons. Those electrons are in turn accelerated and free additional electrons. The result is an avalanche multiplication that permits a electrical conduction through the gas) to produce an easily measured detection pulse, which is fed to the processing and display electronics. This large pulse from the tube makes the G-M counter relatively cheap to manufacture, as the subsequent electronics is greatly simplified. The electronics also generates the high voltage, typically 400–800volts, which has to be applied to the Geiger-Müller tube to enable its operation.

3.3.3 Semiconductor Detectors

A semiconductor detector is physics device that uses a semiconductor (usually silicon or germanium) to measure the effect of incident charged particles or photons.

The operation of a semiconductor detector is analogous to the operation of an ionization chamber. In contrast to ionization chambers, where the incident radiation produces positive ions and electrons, in semiconductor counters radiation produces electrons and holes, contributing to the electric current.

One major difference, of course, is that only 3.5eV is required to produce an electron-hole pair in semiconductor detectors, while 30eV is needed for the ionization of gas. The lower energy increases the number of electron-hole pairs per MeV of radiation and thus increases the sensitivity of radiation detection.

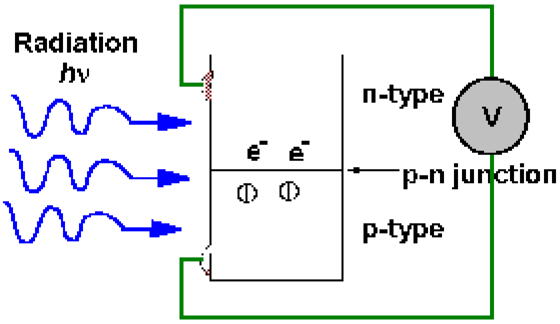


Illustration diagram for semiconductor detector

Semiconductor detectors are considering acceptable sensitive detectors, therefore it has a broad application during recent decades, in particular for gamma and X-ray spectrometry and gas particle detectors.

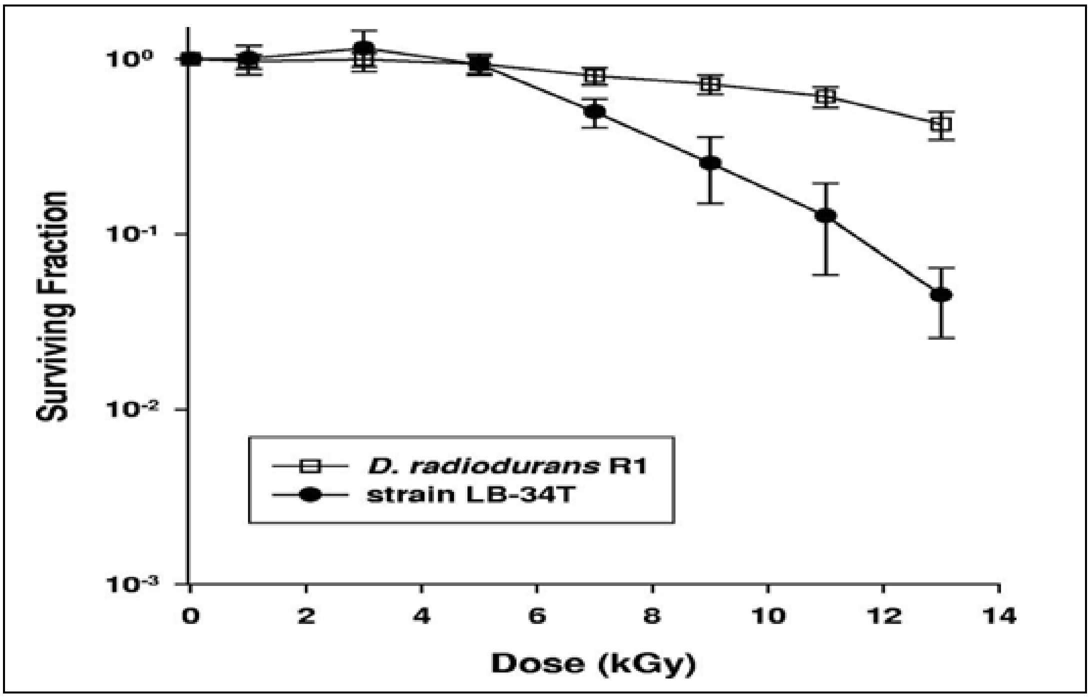
However, very often these methods require the use of much equipment assistance in laboratories and well-trained personnel, and thus cannot be used, for example, in the water environment. Thus, the use of natural systems for sensing, such as microorganisms or bacteria, can be advantageous. It is known that microorganisms (bacteria) might be badly affected by radiation and some of the chemical pollutants.

Such negative effects depend on the radiation level and concentration of pollutants: the damage could range from partial loss of functionality at low doses (concentrations) up to the “death” of bacteria at high doses (concentrations). Therefore, the monitoring of bacteria counts in natural water resources could serve as a simple method for preliminary detection (or screening) of pollutants. In a simple scenario, a low bacteria count in a particular water sample can give an indication (warning) of the presence of some type of contaminant of either a radioactive or a toxic nature,

The development of this new method has allowed estimating radioactive contamination levels on environment.

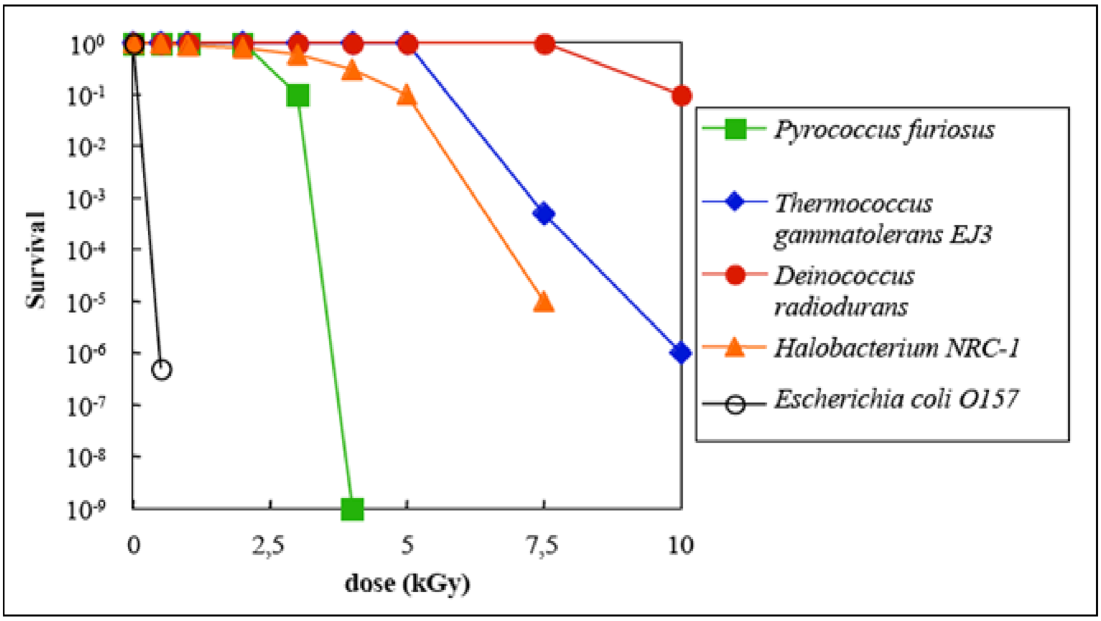
The main effects of radiation are cytotoxic and mutagenic ones, which are principally the result of DNA damage caused during the radiation exposure. This might not always be the case, since environmental organisms, such as Shewanella oneidensis, which encode relatively complex DNA repair systems, are killed at radiation doses that cause relatively little DNA damage.

The survival percentage of Escherichia coli, Deinococcus radiodurans and S. oneidensis due to the effect of ionizing radiation has been using. Results show that 90% of S. oneidensis cells do not survive 70 Gy Gamma-ray radiations, 10% of D. radiodurans cells survive 12,000 Gy, and 10% of E. coli survives 700 Gy. Moreover, S. oneidensis bacteria die after exposure to radiation and desiccate for only one day, whereas similarly treated D. Radiodurans can survive for months.



Survival curves for (radiation resistant bacteria) D. radiodurans strains R1 and LB-34T

Deinococcus radiodurans, as mentioned, is a Gram-positive bacterium well known for its ability to survive extreme doses of ionizing radiation. Though Deinococcus radiodurans is highly resistant to a broad spectrum of DNA damaging agents, it can recover from particularly high doses of ionizing radiation, which is known for producing dsDNA breaks. Since high doses of radiation lead to 150-200 dsDNA breaks per chromosome in Deinococcus radiodurans, radio-resistance is largely due to highly proficient mechanisms of DNA repair. By contrast, Escherichia coli can survive only a few dsDNA breaks at a time.



Survival curves for Pyrococcus furiosus, T. Gamma tolerance, D. Radiodurans, Halobacterium, and E. coli, following exposure to γ radiation

For that, the response of bacteria to radiation pollution, being utilizing to estimate the pollution level and using as a biosensor to detect the radiation pollution in environment.

Chapter Four (Prevention and Reduction)

4.1 Methods of Prevention

Radiation protection or prevention, sometimes known as radiological protection, is the science and practice of protecting people and the environment from the harmful effects of ionizing radiation.

Fundamental to radiation protection is the reduction of expected dose and the measurement of human dose uptake. For radiation, protection and dosimeter assessment the International Committee on Radiation Protection (ICRP) and International Commission on Radiation Units and Measurements (ICRU) have published recommendations and data that are using to calculate the biological effects on the human body, and set regulatory and guidance limits.

There are three factors are control the amount or dose of radiation received from a source. Radiation exposure can be manage by a combination of these factors:

1- Time: Reducing the time of an exposure reduces the effective dose proportionally. An example of reducing radiation doses by reducing the time of exposures might be improving operator training to reduce the time they take to handle a source.

2- Distance: Increasing distance reduces dose due to the inverse square law. Distance can be as simple as handling a source with forceps rather than fingers.

3- Shielding: The term 'biological shield' refers to a mass of absorbing material placed around a reactor, or other radioactive source, to reduce the radiation to a level safe for humans. The effectiveness of a material as a biological shield is relating to its cross-section for scattering and absorption, and to a first approximation is proportional to the total mass of material per unit area interposed along the line of sight between the radiation source and the region to be protected. Hence, shielding strength or "thickness" is conventionally measure in units of g/cm2. The radiation that manages to get through falls exponentially with the thickness of the shield. In x-ray facilities, walls surrounding the room with the x-ray generator may contain lead sheets, or the plaster may contain barium sulfate. Operators view the target through a leaded glass screen, or if they must remain in the same room as the target, wear lead aprons. Almost any material can act as a shield from gamma or x-rays if used in sufficient amounts. The effectiveness of shielding is dependent on the Stopping power of radiation particles, which varies with the type and energy of radiation and the shielding material used. Different shielding techniques are therefore use dependent on the application and the type and energy of the radiation.

Shielding reduces the intensity of radiation depending on the thickness. This is an exponential relationship with gradually diminishing effect as equal slices of shielding material are add. A quantity known as the halving-thicknesses is use to calculate this. The effectiveness of a shielding material in general increases with its atomic number, called Z, except for neutron shielding which is more readily shielded by the likes of Neutron absorbers and moderators such as compounds of Boron e.g. boric acid, cadmium and Carbon & Hydrogen respectively.

Graded-Z shielding is a laminate of several materials with different Z values (atomic numbers) designed to protect against ionizing radiation. Compared to single-material shielding, the same mass of graded-Z shielding has been shown to reduce electron penetration over 60%. It is commonly used in satellite-based particle detectors, offering several benefits:

1- protection from radiation damage
2- reduction of background noise for detectors
3- lower mass compared to single-material shielding

In most countries, a national regulatory authority works towards ensuring a secure radiation environment in society by setting dose limitation requirements that are generally based on the recommendations of the International Commission on Radiological Protection (ICRP). These use the following overall principles:

*Justification: No unnecessary use of radiation is permitted, which means that the advantages must outweigh the disadvantages.

*Limitation: Each individual must be protected against risks that are far too large through individual radiation dose limits.

*Optimization: Radiation doses should all be kept as low as reasonably achievable. This means that it is not enough to remain under the radiation dose limits. As permit holder, you are responsible for ensuring that radiation doses are as low as reasonably achievable, which means that the actual radiation doses are often much lower than the permitted limit.

This policy of prevention is based on the principle that any amount of radiation exposure, no matter how small, can increase the chance of negative biological effects such as cancer. It is also based on the principle that the probability of the occurrence of negative effects of radiation exposure increases with cumulative lifetime dose. Different types of ionizing radiation interact in different ways with shielding material.

Radiation protection instruments: - Practical radiation measurement using calibrated radiation protection instruments is essential in evaluating the effectiveness of protection measures, and in assessing the radiation dose likely to be received by individuals. The measuring instruments for radiation protection are both "installed" (in a fixed position) and portable (hand-held or transportable).

Installed instruments: - Installed instruments are fixed in positions which are known to be important in assessing the general radiation hazard in an area. Examples are installed "area" radiation monitors, Gamma interlock monitors, personnel exit monitors, and airborne particulate monitors.

The area radiation monitor will measure the ambient radiation, usually X-Ray, Gamma or neutrons; these are radiations which can have significant radiation levels over a range in excess of tens of metres from their source, and thereby cover a wide area.

Gamma radiation "interlock monitors" are used in applications to prevent inadvertent exposure of workers to an excess dose by preventing personnel access to an area when a high radiation level is present. These interlock the process access directly.

Airborne contamination monitors measure the concentration of radioactive particles in the ambient air to guard against radioactive particles being ingested, or deposited in the lungs of personnel. These instruments will normally give a local alarm, but are often connected to an integrated safety system so that areas of plant can be evacuated and personnel are prevented from entering an air of high airborne contamination.

Personnel exit monitors (PEM):- are use to monitor workers who are exiting a "contamination controlled" or potentially contaminated area.

These can be in the form of hand monitors, clothing frisk probes, or whole body monitors. These monitor the surface of the workers body and clothing to check if any radioactive contamination has been deposited. These generally measure alpha or beta or gamma, or combinations of these.

The UK National Physical Laboratory publishes a good practice guide through its Ionizing Radiation Metrology Forum concerning the provision of such equipment and the methodology of calculating the alarm levels to be used.

Portable instruments:- Hand-held ion chamber survey meter in use. Portable instruments are hand-held or transportable. The hand-held instrument is generally used as a survey meter to check an object or person in detail, or assess an area where no installed instrumentation exists. They can also be used for personnel exit monitoring or personnel contamination checks in the field. These generally measure alpha, beta or gamma, or combinations of these.

4.2. Reduction of Radioactive Contaminants

Radiation Pollution reduction can be doing at various levels, including the handling and treatment of radiation waste, the control and reducing of nuclear accidents, as well as the control and minimization of personal exposure to radiation at an individual level.

Treatment or reduction of radiation waste cannot be doing through degradation by chemical or biological processes. Additionally, many radioactive materials have very long half-life (time necessary for half of the material to degrade or transform into non-radioactive materials) and thus radiation waste may pose a risk for many years after it produced. There are only few options for radiation waste treatment involving:

1- Containment of the waste in radiation-shielded containers usually buried under ground
2- Isolation of radiation waste in remote locations such as remote caves or abandoned mines - which may also involve the use of some kind of barriers (shields),
3- When the first two alternatives are not possible, the waste may be diluted till background values are achieved.
4- Keep the radiation waste in cold places, away from any heating source, because the heat increases the amount of radiation and thus may increase the health risk.

At individual levels, there are measures you may take to prevent and/or reduce radiation pollution that may affect you and your family. Here are some examples:

First, testing of your home for radon may be doing by each person using inexpensive testing kits or by specialized consulting services. If radiation seems to be an issue (a higher than background value of radon in home is found), a preferred radon reduction technique is the installation of a special system called active soil depressurization (ASD). This system contains a vent pipe with an inline centrifugal fan that operates continuously to vent radon and other intruding gases from beneath the house. Thus, the system may be efficient to block the intrusion into homes not only of radon, but also of other toxic chemicals (non-radioactive) that may get from the subsurface into indoor breathing air.

4.3. Radioactive Waste Management

Treatment and conditioning processes are use to convert radioactive waste materials into a form that is suitable for its subsequent management, such as transportation, storage and final disposal. The principal aims are to:

*Minimise the volume of waste requiring management via treatment processes.

*Reduce the potential hazard of the waste by conditioning it into a stable solid form that immobilises it and provides containment to ensure that the waste its can be safely handle during transportation, storage and final disposal.

It is important to note that, while treatment processes such as compaction and incineration reduce the volume of waste, the amount of radioactivity remains the same. As such, the radioactivity of the waste will become more concentrated as the volume it is reduced.

Conditioning processes such as cementation and vitrification are used to convert waste into a stable solid form that is insoluble and will prevent dispersion to the surrounding environment. A systematic approach incorporates:

* Identifying a suitable matrix material such as; cement, bitumen, polymers or borosilicate glass - that will ensure stability of the radioactive materials for the period necessary. The type of waste being conditioned determines the choice of matrix material and packaging.

* Immobilising the waste through mixing with the matrix material

* Packaging the immobilised waste, for example in; metallic drums, metallic container or concrete boxes or containers, copper canisters.

The choice of process used is dependent on the level of activity and the type (classification) of waste. Each country's nuclear waste management policy and its national regulations also influence the approach taken.

Incineration

Incineration of combustible wastes can be applied to both radioactive and other wastes. In the case of radioactive waste, it has been used for the treatment of low-level waste from nuclear power plants, fuel production facilities, research centres (such as biomedical research), medical sector and waste treatment facilities.

Following the separation of combustible waste from non-combustible constituents, the waste is incinerated in a specially engineered kiln up to around 1000^{o}C. Any gases produced during incineration are treated and filtered prior to emission into the atmosphere and must conform to international standards and national emissions regulations.

Following incineration, the resulting ash, which contains the radionuclides, may require further conditioning prior to disposal such as cementation or bituminisation. Compaction technology may also be used to further reduce the volume, if this is cost-effective. Volume reduction factors of up to around 100 are achieved, depending on the density of the waste.

Incineration technology is subject to public concern in many countries as local residents worry about what is being emitted into the atmosphere. However, modern incineration systems are well engineered, high technology processes designed to completely and efficiently burn the waste whilst producing minimum emissions. The incineration of hazardous waste (e.g. waste oils, solvents) and non-hazardous waste (municipal waste, biomass, tyres, sewage sludge) is also practised in many countries.

Cementation

Cementation through the use of specially formulated grouts provides the means to immobilise radioactive material that is on solids and in various forms of sludges and precipitates/gels (flocks) or active materials.

In general the solid wastes are placed into containers. The grout is then added into this container and allowed to set. The container with the now monolithic block of concrete/waste is then suitable for storage and disposal. Similarly in the case of sludges and flocks, the waste is placed in a container and the grouting mix, in powder form, is added. The two are mixed inside the container and left to set leaving a similar type of product as in the case of solids, which can be disposed of in a similar way.

This process has been used for example in small oil drums and 500-litre containers for intermediate-level wastes and has been extended to ISO shipping containers for low-level waste materials. The technology is being used in the immobilisation of many toxic and hazardous wastes that arise outside the nuclear industry and has the potential to be used in many more cases.

Vitrification

The immobilisation of high-level waste (HLW) requires the formation of an insoluble, solid waste form that will remain stable for many thousands of years. In general borosilicate glass has been chosen as the medium for dealing with HLW. The stability of ancient glass for thousands of years highlights the suitability of borosilicate glass as a matrix material.

This type of process, referred to as vitrification, has also been extended for lower level wastes where the type of waste or the economics have been appropriate. Most high-level wastes other than spent fuel itself, arise in a liquid form from the reprocessing of spent fuel. To allow incorporation into the glass matrix this waste that initially dried which turns it into a solid form. This product then incorporated into molten glass in a stainless container and allowed to cool, giving a solid matrix. The containers and then welded closed and are ready for storage and final disposal.

This process is currently being using in France, Japan, the Former Soviet Union, UK and USA and is seen as the preferred process for management of separated HLW arising from reprocessing.

In-situ vitrification also has been investigated as a means of 'fixing' activity in contaminated ground as well as creating a barrier to prevent further spread of contaminants.

Several other alternative ceramic processes have also developed which also achieve the desired quality of product.