كلية العلوم

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Write about ,in details, with draw:

Deterministic and Stochastic effects of Radiations

Types of ionizing radiation

Interaction of radiation with matter

Equivalent Dose

Radiation protection

Geiger counter

Metabolism and Biological Effects of Deposited Radionuclides

Answers

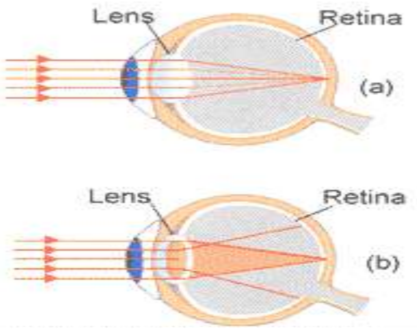
Deterministic and Stochastic effects of Radiations

6.5.1 Deterministic effects:

A very high dose to the whole body can cause death within weeks. For example, an absorbed dose of 5 gray or more received instantaneously would probably be lethal, unless treatments were given, because of damage to the bone marrow and the gastro-intestinal tract. Appropriate medical treatment may save the life of a person exposed to 5 gray, but a whole body dose of, say, 50 gray would almost certainly be fatal even with medical attention. A very high dose to a limited area of the body might not prove fatal, but other early effects could occur. For example, an instantaneous absorbed dose of 5 gray to the skin would probably cause erythema - painful reddening of the skin - within a week or so, whereas a similar dose to the reproductive organs might cause sterility.

These types of effect are called deterministic effects: they occur only if the dose or dose rate is greater than some threshold value, and the effect occurs earlier and is more severe as the dose and dose rate increase. Deterministic effects in an individual can be identified clinically to be the result of radiation exposure.

One type of deterministic effects occurs a longer time after exposure. Such effects are not usually fatal, but can be disabling or distressing because the function of some parts of the body may be impaired or other non-malignant changes may arise. The best-known examples are cataracts (opacity in the lens of the eye) and skin damage (thinning and ulceration). High absorbed doses of several gray are normally required to induce these conditions.



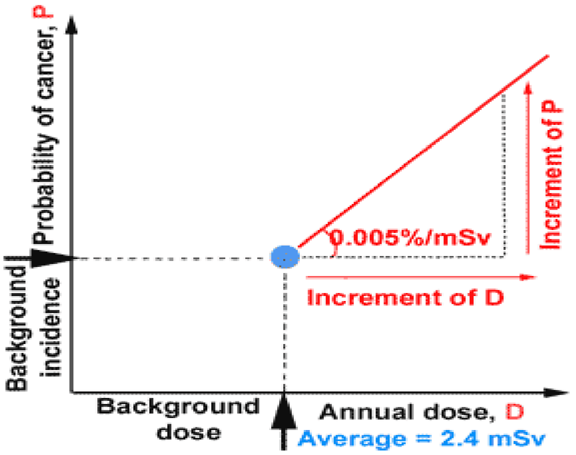
(a) Normal lens-light is focussed normally on the retina
(b) lens with cataract-opacity of the lens blocks or distorts light from being focussed on the retina, resulting in reduced vision

6.5.2 Stochastic effects:

If the dose is lower, or is delivered over a longer period of time, there is a greater opportunity for the body cells to repair, and there may be no early signs of injury. Even so, tissues may still have been damaged. In such a way, that the effects appear only later in life (perhaps decades later), or even in the descendants of the irradiated person.

These types of effect are called stochastic effects: they are not certain to occur, but the likelihood that they will occur increases as the dose increases, whereas the timing and severity of any effect does not depend on the dose. Because radiation is not the only known cause of most of these effects, it is normally impossible to determine clinically whether an individual case is the result of radiation exposure or not.

The most important of these stochastic effects is cancer, which is always serious and often fatal. Although the exact cause of most cancers remains unknown or poorly understood, exposure to agents such as tobacco smoke, asbestos and ultraviolet radiations, as well as ionizing radiation, are known to play a role in inducing certain types of cancer. The development of cancer is a complex, multistage process that usually takes many years. Radiation appears to act principally at the initiation stage, by introducing certain mutations in the DNA of normal cells in tissues. These mutations allow a cell to enter a pathway of abnormal growth that can sometimes lead to the development of a malignancy.



Given that we cannot distinguish between those cancer cases resulting from radiation exposure and those with other causes, how can we calculate the risk of cancer from radiation? In practice, we have to use epidemiology - the statistical study of the incidence (the number of cases and their distribution) of specific disorders in specific population groups. Suppose that we know the number of people in an irradiated group and the doses they have received. Then by observing the occurrence of cancer in the group and comparing with the doses and the number of cancers expected in an otherwise similar but unirradiated group, we can estimate the raised risk of cancer per unit dose. This is commonly called a risk factor. It is most important to include data for large groups of people in these calculations so as to minimize the statistical uncertainties in the estimates and take account of factors, such as age and gender that affect the spontaneous development of cancer.

Not all cancers are fatal. Average mortality from radiation-induced thyroid cancer is about 10 per cent (although it is much lower -less than 1 per cent - for the cases caused in children and teenagers by the Chernobyl accident), from breast cancer about 50 per cent, and from skin cancer about 1 per cent. Overall, the total risk of inducing cancer by uniformly irradiating the whole body is about half as great again as the risk of inducing a fatal cancer. In radiological protection the risk of fatal cancer is of more concern because of its extreme significance. The use of fatal cancer risks also makes it easier to compare them with the other fatal risks encountered in life. In contrast, comparisons of non-fatal risks are fraught with difficulty.

Types of ionizing radiation

Ionizing radiation can ionize matter either directly or indirectly because its energy exceeds the ionization potential of matter. It contains two major categories:

Directly ionizing radiation consists of several groups of charged particles, such as light charged particles (electrons and positrons), heavy charged particles (protons, deuterons, and alpha particles), and heavier charged particles (e.g., carbon-12).

Indirectly ionizing radiation consists of photons (x rays, gamma rays) and neutrons.

5.1.1 Electromagnetic Radiation:

Electric and magnetic fields oscillate together but perpendicular to each other and the electromagnetic wave moves in a direction perpendicular to both of the fields.

Light, electricity, and magnetism are manifestations of the same thing called **electromagnetic radiation**. The electric and magnetic fields oscillate at right angles to each other and the combined wave moves in a direction perpendicular to both of the electric and magnetic field oscillations. This energy also comes in many forms that are not detectable with our eyes such as infrared (IR), radio, X-rays, ultraviolet (UV), and gamma rays.

We feel infrared light as heat and our radios pick up the messages encoded in radio waves emitted by radio stations. Ultraviolet light has high enough energy to damage our skin cells, so our bodies will produce a darker pigment in our skin to prevent exposure of the deeper skin cells to the UV (we tan as a defense mechanism). The special bulbs called ``black lights" produce a lot of UV and were used by hospitals to kill bacteria, amoebas, and other micro-organisms. X-rays are produced by very hot things in space. X-rays have more energy than UV, so they can pass through skin, muscles, and organs. They are blocked by bones, so when the doctor takes your X-ray, the picture that results is the shadow image of the X-rays that passed through your body. Because X-rays have such high energy, they can damage or kill cells. A few brief exposures to low-intensity X-rays are okay. The X-ray technician would be exposed to thousands of X-ray exposures if s/he did not use some sort of shielding. Gamma rays are the most energetic form of electromagnetic radiation and are produced in nuclear reactions.

5.1.2 X-ray:

X-radiation (composed of X-rays) is a form of electromagnetic radiation. X-rays have a wavelength in the range of 10 to 0.01 nanometers, corresponding to frequencies in the range 30 peta hertz to 30 exa hertz (3×10^{16} Hz to 3×10^{19} Hz) and energies in the range 120 eV to 120 keV. They are shorter in wavelength than UV rays. In many languages, X-radiation is called Röntgen radiation after Wilhelm Conrad Röntgen, who is generally credited as their discoverer, and who had called them X-rays to signify an unknown type of radiation.

X-rays can penetrate solid objects, and their largest use is to take images of the inside of objects in diagnostic radiography and crystallography. As a result, the term X-ray is metonymically used to refer to a radiographic image produced using this method, in addition to the method itself. X-rays are a form of ionizing radiation, and exposure to them can be a health hazard.

X-rays from about 0.12 to 12 keV (10 to 0.10 nm wavelength), are classified as soft X-rays, and from about 12 to 120 keV (0.10 to 0.010 nm wavelength) as hard X-rays, due to their penetrating abilities.

5.1.3 Gamma ray:

Gamma rays (denoted as γ) are electromagnetic radiation of high frequency (very short wavelength). They are produced by sub-atomic particle interactions such as electron-positron annihilation, neutral pion decay, radioactive decay, fusion, fission or inverse Compton scattering in astrophysical processes. Gamma rays typically have frequencies above 10^{19} Hz and therefore energies above 100 keV and wavelength less than 10 picometers, often smaller than an atom. Gamma radioactive decay photons commonly have energies of a few hundred KeV, and are almost always less than 10 MeV in energy.

Because they are a form of ionizing radiation gamma rays can cause serious damage when absorbed by living tissue, and are therefore a health hazard.

In the past, the distinction between X-rays and gamma rays was based on energy (or equivalently frequency or wavelength), the latter being considered a higher-energy version of the former. However, high-energy X-rays produced by linear accelerators ("linacs") and astrophysical processes now often have higher energy than gamma rays produced by radioactive gamma decay. (In fact, one of the most common gamma-ray emitting isotopes used in nuclear medicine, technetium-99m produces gamma radiation of about the same energy (140 kev) as produced by a diagnostic X-ray machine, and significantly lower energy than the therapeutic treatment X-rays produced by linac machines in cancer radiotherapy.) Because of this overlap in energy ranges, the two types of electromagnetic radiation are now usually defined by their origin: X-rays are emitted by electrons outside the nucleus (and when produced by therapeutic linacs are often simply called "photons"), while gamma rays are specifically emitted by the nucleus (that is, produced by gamma decay). In theory, there is no lower limit to the energy of such photons, and thus "ultraviolet gamma rays" have been postulated. In certain fields such as astronomy, gamma rays and X-rays are still sometimes defined by energy, as the processes which produce them may be uncertain.

5.2 Charged Particulate radiation:

Particle radiation is the radiation of energy by means of fast-moving subatomic particles. Particle radiation is referred to as a particle beam if the particles are all moving in the same direction, similar to a light beam.

Due to the wave-particle duality, all moving particles also have wave character. Higher energy particles more easily exhibit particle characteristics, while lower energy particles more easily exhibit wave characteristics.

5.2.1 Particles can be electrically charged or uncharged:

Particle radiation can be emitted by an unstable atomic nucleus (radioactive decay) in the form of a positively charged alpha particle (α), a positively or negatively charged beta particle (β) (the latter being more common) , a photon (called a gamma particle, γ), or a neutron. Neutrinos are produced in beta decay in addition to beta particles; they interact with matter only very weakly. Photons, neutrons, and neutrinos are uncharged particles. The decay events of proton emission and cluster decay also emit (groups of) nucleons as charged particles, but are comparatively rare.

Other forms of particle radiation, including mesons and muons, occur naturally when (cosmic rays) impact the atmosphere. Mesons are found at high altitudes, but muons can be measured even at sea level.

Charged particles (electrons, mesons, protons, alpha particles, heavier atomic ions, etc.) can be produced by particle accelerators. Ion irradiation is widely used in the semiconductor industry to introduce dopants into materials, a method known as ion implantation.

Particle accelerators can also produce neutrino beams. Neutron beams are mostly produced by nuclear reactors. For the production of electromagnetic radiation, there are many methods, depending upon the wave length .

Interaction of radiation with matter

5.4 Interaction of radiation with matter:

5.4.1Alpha Radiation

Since the alpha particle is basically a He nucleus (2 protons & 2 neutrons), it is the largest and most massive type of radiation (except for fission fragments). Additionally, the interaction of alpha particles with matter is very strong due to the alpha particle's electrical charge of 2 units. Alpha trajectories can be deviated by both electric and magnetic fields. The major energy loss mechanism for alpha particles is electronic excitation and ionization. The specific ionization of an alpha particle is very high, in the order of thousands of ion pairs per centimetre of air.

Because of the strong interaction of alpha particles with matter, they have a short range; a sheet of paper, the surface layer of dead skin (epidermis), or a few centimetres of air can easily stop them. Consequently, there is no concern for external irradiation of people. However, when gamma radiation is emitted together with alpha particles, precautions against external irradiation caused by gamma rays should be taken into account.

When inhalation or ingestion of an alpha emitting radioactive material occurs, internal irradiation becomes a major concern. The alpha particles interact strongly with the surrounding internal tissues (live tissue). All of their energy is absorbed inside the body, potentially causing damage to the cells. Therefore, special precautions are taken when handling open, volatile sources of alpha emitting radionuclides.

5.4.2 Electron Interactions:

The interaction and transfer of energy from photons to tissue has two phases. The first is the "one-shot" interaction between the photon and an electron in which all or a significant part of the photon energy is transferred; the second is the transfer of energy from the energized electron as it moves through the tissue. This occurs as a series of interactions, each of which transfers a relatively small amount of energy.

Several types of radioactive transitions produce electron radiation including beta radiation, internal conversion (IC) electrons, and Auger electrons. These radiation electrons interact with matter (tissue) in a manner similar to that of electrons produced by photon interactions.

In photoelectric interactions, the energy of the electron is equal to the energy of the incident photon less the binding energy of the electron within the atom. In Compton interactions, the relationship of the electron energy to that of the photon depends on the angle of scatter and the original photon energy. The electrons set free by these interactions have kinetic energies ranging from relatively low values to values slightly below the energy of the incident photons.

As the electrons leave the interaction site, they immediately begin to transfer their energy to the surrounding material, as shown below. Because the electron carries an electrical charge, it can interact with other electrons without touching them. As it passes through the material, the electron, in effect, pushes the other electrons away from its path. If the force on an electron is sufficient to remove it from its atom, ionization results. In some cases, the atomic or molecular structures are raised to a higher energy level, or excited state. Regardless of the type of interaction, the moving electron loses some of its energy.

Most of the ionization produced by x- and gamma radiation is not a result of direct photon interactions, but rather of interactions of the energetic electrons with the material. For example, in air, radiation must expend an average energy of 33.4 eV per ionization. Consider a 50-keV x-ray photon undergoing a photoelectric interaction. The initial interaction of the photon ionizes one atom, but the resulting energetic electron ionizes approximately 1,500 additional atoms.

5.4.3 Positron Interactions

Recall that a positron is the same size as an electron, but has a positive charge. It is also different from the electron in that it is composed of what is referred to as antimatter. This leads to a type of interaction that is quite different from the interactions among electrons.

The interaction between a positron and matter is in two phases, as illustrated below. These are ionization and annihilation. As the energetic positron passes through matter, it interacts with the atomic electrons by electrical attraction. As the positron moves along, it pulls electrons out of the atoms and produces ionization. A small amount of energy is lost by the positron in each interaction. In general, this phase of the interaction is not too unlike the interaction of an energetic electron, but the positron pulls electrons as it races by and electrons push electrons away-from the path. Also, when the positron has lost most of its kinetic energy and is coming to a stop, it comes into close contact with an electron and enters into an annihilation interaction.

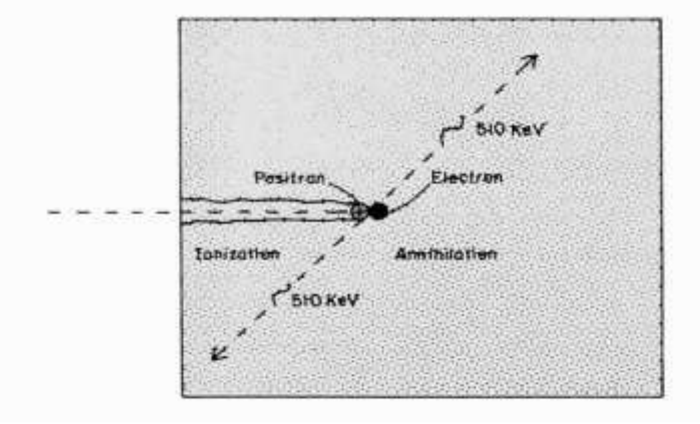


Fig.5.4 A Positron Interaction That Produces Annihilation Radiation

The annihilation process occurs when the antimatter positron combines with the conventional-matter electron. In this interaction, the masses of both particles are completely converted into energy. The relationship between the amount of energy and mass is given by **$E= mc^2$.**

The energy equivalent of one electron or positron mass is 511 keV. The energy that results from the annihilation process is emitted from the interaction site in the form of two photons, each with energy of 511 keV. The pair of photons leave the site in opposite directions. With special imaging equipment it is possible to capture both photons and to determine the precise three-dimensional location of the interaction site. Since the range of a positron, like that of an electron, is relatively short, the site of interaction is always very close to the location of the radioactive nuclei.

A- Photoelectric Effect

An electron is emitted from an atom (ionization process) with energy equal to the energy of the gamma ray. The electron then moves through matter and loses its energy as described for beta interactions. This is the predominant effect at low gamma energies.

B- Compton Scattering

The gamma ray interacts with an electron, causing an increase in the electron's energy. A new gamma ray with a smaller energy is then emitted. The electron interacts as explained earlier. The new gamma ray can escape from the matter or can be absorbed through the photoelectric effect. The Compton effect is the predominant effect at intermediate gamma energies.

C- Pair Production

High-energy gamma rays are absorbed and two particles are created (an electron and a positron) and share the energy of the gamma ray. The electron interacts with matter, as explained above for beta interaction. The positron loses its energy through ionization or excitation. If it is stationary, the positron interacts with an electron creating two gamma rays with energies of 511 keV each (annihilation radiation). These two gamma rays can escape or interact with matter through the Compton scattering or Photoelectric effect.

The absorption of gamma rays obeys an exponential law. There is no definite range of absorption for gamma rays in matter. Protection against gamma rays (as well as against X-rays) is best obtained with heavy materials (lead or other metals), as well as with large quantities of concrete or other materials. For example, the earth's atmosphere protects us against high-energy gamma rays and other high-energy radiation coming from outer space.

5.4.5 Interaction of Neutrons:

Neutrons, which have rest mass but are electrically neutral, undergo weak interactions with matter. Their mechanism of interaction is through collisions. Having a mass similar to that of the protons, their greatest interactions occur with atoms of Hydrogen (like billiard balls colliding with each other). After a number of collisions, the neutron's energy decreases and is finally totally absorbed. Due to the high content of water in human tissue, neutrons are considered very hazardous. Protection against neutrons can be obtained with materials containing H or other light nuclei (like water, wax, or concrete).

The interaction of neutrons with boron nuclei is the main mechanism used for neutron detection:

B-10 + neutron → Li-7 + alpha + energy

As a result of this nuclear reaction, alpha particles and gamma rays are emitted with energies of 480 keV and could be detected by the instrument. Therefore, detection of neutrons is an indirect process.

Equivalent Dose

The equivalent dose, HT,R , for tissue, T, and radiation type, R, is the product of absorbed dose for this radiation type, DR, and the radiation weighting factor, WR

$$H_{T,R} = D_R W_R \qquad (4)$$

The special unit for HT,R depends on the special unit used for DR as shown in the following examples:

1. If DR is given in rad, then the special unit for HR is rem, and the dose in rem is numerically equal to the dose in rad multiplied by the appropriate modifying factors, Q and N. There is no abbreviation for the unit rem. As in the case for the unit rad, equivalent dose in rem is slowly disappearing from usage.

2. If DR is given in gray, then the special unit for HR is the sievert, and the dose in sievert is numerically equal to the dose in gray multiplied by the appropriate radiation weighting factor. The abbreviation for sievert is Sv.

Radiation protection

Exposure to ionizing radiation occurs in many occupations. Artificial sources of radiation are commonly used in the manufacturing and service industries, in areas of defense, in research institutions, and in universities, as well as in the nuclear power industry. Moreover, they are extensively used by physicians and health professionals.

Approaches to protection against ionizing radiation are remarkably consistent throughout the world. This is due largely to the existence of well established and internationally recognized systems:

1- The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) regularly reviews the natural and artificial sources of radiation in the environment to which people are exposed, the radiation exposure due to those sources, and the risks associated with that exposure. It reports its findings to the UN General Assembly on an ongoing basis.

2- The International Commission on Radiological Protection (ICRP) is a non-governmental scientific organization founded in 1928, which has regularly published recommendations for protection against ionizing radiation. Its authority derives from the scientific standing of its members and the merit of its recommendations. It bases its estimates of the probability of fatal cancer mainly on studies of the Japanese survivors of the atomic bombs and their assessment by bodies such as UNSCEAR.

3- The International Atomic Energy Agency (IAEA) has a statutory function to establish safety standards, where appropriate in collaboration with other relevant international organizations. In doing this, it relies heavily on the work of UNSCEAR and ICRP. It also has a responsibility for providing for the application of those standards at the request of a State and it does this through various mechanisms, including the provision of services and training.

General principles

ICRP recommends system of radiological protection based on three central requirements. Each of these involves social considerations - explicitly in the first two and implicitly in the third so there is considerable need for the use of judgment:

1- Justification of a practice

Practices are activities involving the deliberate use of radiation. Such uses are clearly defined and can be regulated. On the other hand, we can generally do nothing practical to reduce the normal levels of dose from natural radiation, although it is appropriate to intervene when people are exposed to high levels of radon in their homes or at work.

No practice involving exposure to radiation should be adopted unless it produces at least sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes.

The first requirement in the system of radiological protection for practices emphasizes the obvious need to consider harmful costs in the light of the benefits. In most cases, radiation effects are just some of a number of possible harmful outcomes that make up part of the overall social and economic costs. If there are other ways to achieve the same end, with or without radiation, it is important to analyze the costs and benefits of the alternatives before making a final decision in favor of one or the other. The issues that arise in the process of justification extend far beyond radiological protection and may be illustrated by the arguments about the nuclear power program. The radiological consequences of the program include the discharge of radioactive substances to the environment and the doses received by workers in the nuclear power industry. In addition, a full analysis would deal with the potential for nuclear reactor accidents, as well as the creation of radioactive wastes. Account should also be taken of doses and accidents to uranium miners (who are often in countries other than those using the uranium).

An assessment should then be made of the consequences of doing without the energy provided by nuclear power or of using alternative methods to produce it - with coal for instance. Generating electric power from coal creates large volumes of waste and releases gases that worsen the greenhouse effect. Coal-fired power stations also discharge toxic substances and natural radioactive materials, coal miners suffer occupational diseases, and there is the potential for mining accidents. A complete analysis would also need to consider several strategic and economic factors: the diversity, security, availability, and reserves of various fuels; the construction and operating costs of various types of power station; the expected demand for electricity; and the willingness of people to work in a particular industry

2- Optimization of protection

In relation to any particular source of radiation within a practice, the dose to any individual from that source should be below an appropriate dose constraint, and all reasonable steps should be taken to adjust the protection so that exposures are **"as low as reasonably achievable" ALARA**, economic and social factors being taken into account. Dose constraints or guidance levels are also appropriate for medical exposures of patients, the objective being to minimize doses in a sensible way. Some routine medical procedures can give significant doses (i.e. several mSv) and, importantly, can vary greatly from hospital to hospital. The use of guidance levels can provide a practical means of reducing doses to patients without a reduction in the diagnostic information available to physicians.

Since we assume that no radiation dose is entirely free from risk, it is important to pay attention to all doses and to reduce them whenever it is reasonably achievable. Eventually the point must come when further reductions in dose become unreasonable, because social and economic costs would outweigh the value of the reductions. On the other hand, the benefits and risks associated with a particular practice are often not distributed evenly in society, and so this second requirement - the optimization of protection recommended by ICRP - also includes a constraint on the procedure, in the form of restrictions on doses or risks to people so as to prevent inequitable exposures from radiation.

Optimization of protection has been increasingly influential during the past two decades throughout the world and, in most countries; the average annual dose to radiation workers is well below (i.e. by a factor of ten or more) the 20 mSv per year that ICRP has recommended. Some groups of workers receive doses a few times the average, and some workers receive more than 20 mSv/a, but the number doing so is a very small percentage of the total. Analysis by UNSCEAR shows that the average annual dose to workers from man-made sources is 0.6 mSv, whereas the average annual dose to workers from enhanced natural sources (e.g. in mining) is higher at 1.8 mSv

3-Justification and Optimization of intervention

The proposed intervention should do more good than harm, that is, the benefits resulting from the reduction in dose should be sufficient to justify the harm and the costs, including social costs, of the intervention.

The form, scale, and duration of the intervention should be chosen so that the net benefit of the reduction of dose, that is, the benefit of the reduction in dose less the costs of the intervention, should be as large as reasonably achievable. The ICRP system is widely incorporated into national legislation throughout the world.

The International Basic Safety Standards (BSS)

The BSS, published in 1996, are based primarily on the ICRP system of radiological protection described above. These standards lay down detailed requirements for occupational, medical and public exposures, and specify dose limits and exemptions. They also specify requirements for ensuring the safety of radioactive sources and for dealing with nuclear emergencies. IAEA Safety Guides give more detailed guidance on how the requirements should be met in particular situations. Most countries apply these standards in their own legislation and regulatory requirements.

The BSS specify technical, scientific and administrative requirements for the safe use of radiation. However, these requirements presuppose that certain basic arrangements are in place to control uses of radiation. These basic arrangements are sometimes referred to as 'infrastructure for safety', and include such things as laws and regulations on the use of radiation and radioactive materials, and a regulatory body responsible for making sure these are followed.

In countries with nuclear power programs, this infrastructure has normally been developed. But this infrastructure is necessary for any uses of radiation, not just nuclear power.

Almost all countries make some use of radiation in medicine or industry. Around the time the BSS were published, the IAEA realized that many countries without nuclear power programs did not have a proper safety infrastructure, and so a major project was initiated to assist them in improving their capabilities to manage these uses of radiation safely.

Geiger counter

As shown in Fig. (5.9), it consists of a cylindrical metal tube filled with a certain type of gas. A long wire runs down the center and is kept at a high positive voltage (~ 10^3V) with respect to the outer cylinder. The voltage is just slightly less than that required ionizing the gas atoms. When a charged particle enters through a thin "window" at one end of the tube, it ionizes a few atoms of the gas. The freed electrons are attached toward the positive wire and as they are accelerated they strike and ionize additional atoms. An "avalanche" of electrons is quickly produced, and when it reaches the wire anode it produces a voltage pulse. The pulse, after being amplified, can be sent to an electronic counter, which keeps track of how many particles have been detected. Or the pulses can be sent to a loudspeaker and each detection of a particle is heard as a "click".

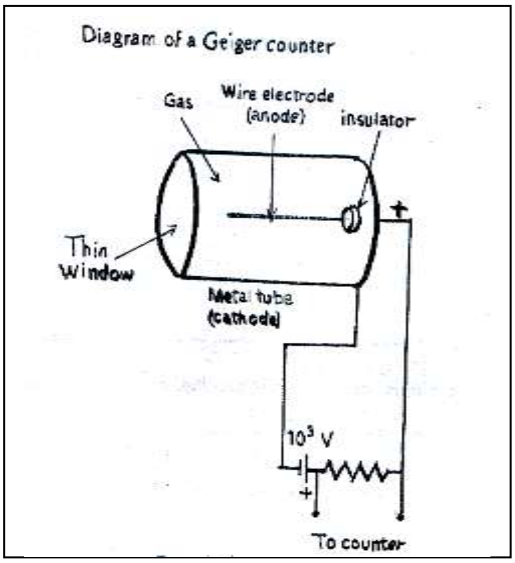


Diagram of a Geiger counter

Metabolism and Biological Effects of Deposited Radionuclides

The text has, to this point, dealt entirely with the delivery of ionizingradiation from important contributor to the dose received by biological systems. This source comprises all manmade as well as naturally occurring radionuclides.

Obviously these radionuclides can also contribute to the dose received from externally located sources. Naturally occurring radioactivity in the Earth's crust will always be a significant contributor to externally delivered dose, and it cannot be more than marginally controlled.

Those radionuclides that are able to enter the living cell by eithermetabolic or other processes give rise to localized dose that may be very high and that may be qualitatively different in its effect from the dose delivered externally, since often these deposited radioisotopes are sources of high LET radiations.

Only in rather unusual circumstances will living systems, particularly human beings, be exposed to high LET radiation from external sources. Such circumstances might include occupational exposure around large experimental accelerators or the occupational exposure of astronauts to high-energy, heavy charged particles in extraterrestrial space. Such exposures to high LET radiations will be of little significance to the large proportion of the population. On the other hand, when radionuclides are incorporated into living systems, the high LET radiations produced by their disintegration, which would otherwise be unimportant, become very