PHS 357 – HEALTH PHYSICS I

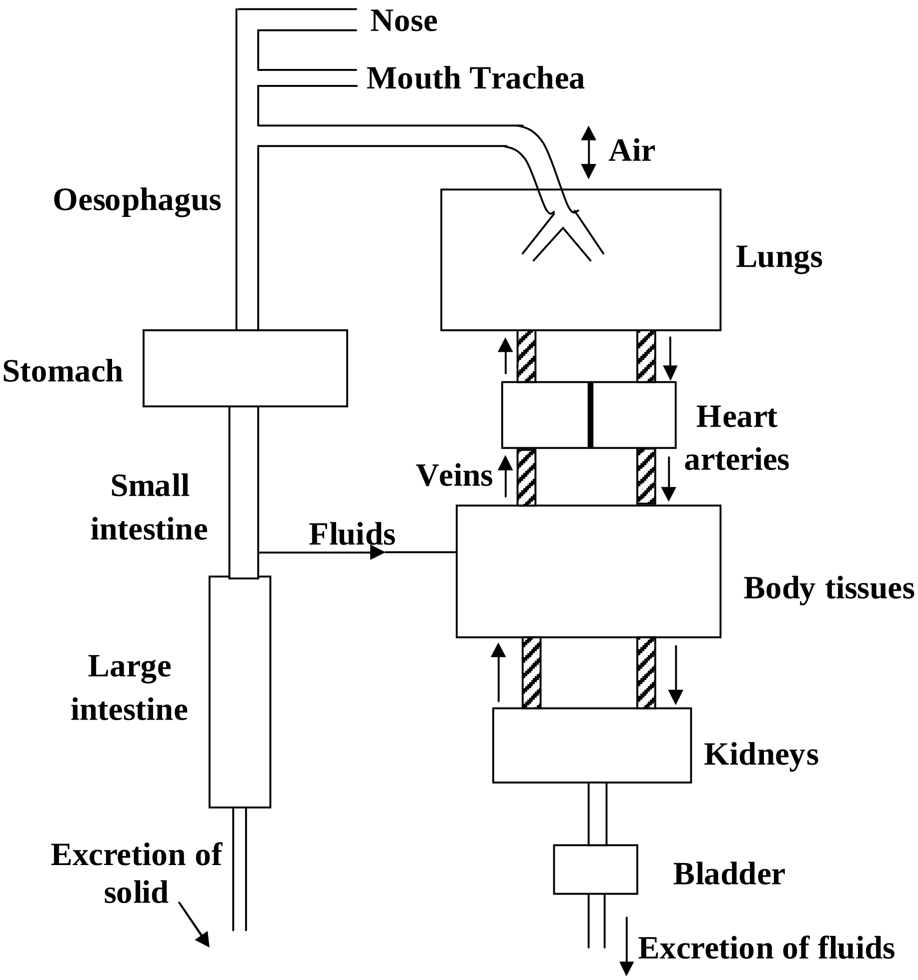

Fig 1: Schematic illustration of human physiology

THE CIRCULATORY SYSTEM

The heart is actually two pumps; the left side pumps the blood through the arteries to the tissues. The nourishment is transferred from the tissues to the cells via the tissue fluids. The blood after passing through the tissues returns to the right side of the heart via the veins. The blood is then pumped to the lungs where it becomes oxygenated before returning to the left side of the heart again.

The blood in the arteries contains a lot of oxygen and is bright red in colour while the blood returning from the tissues contains very little oxygen and is dark red in colour. The body contains about 5 litres of blood which circulates on the average once a minute.

There are three types of blood cells, each performing an essential function. The red cells (erythrocytes), white cells (granulocytes + lymphocytes) and platelets (thrombocytes). The red cells transport the food and oxygen needed by the body.

The white cells serve as means of defence against infection by digesting micro-organisms. Platelets play a vital role in the formation of cloths at the site of injuries.

THE RESPIRATORY SYSTEM

Respiration is the method by which oxygen is taken into the lungs and carbondioxide (CO_2) eliminated. The oxygen is absorbed by the blood as it passes through the lungs and carried to the tissues as described above. The tissues produce CO_2 as a gaseous waste product and this is carried back by the blood to the lungs and breathed out. The volume of air breathed per day is approximately 20 cubic metres, of which half is usually considered to be breathed during the eight hours at work.

In the process of respiration, man inhales many ‘foreign’ substances either in the form of gaseous or particulate materials (i.e. airborne dusts). Gases pass freely into the lungs and enter the blood stream to a greater or lesser extent depending on their solubility. In the case of particulate matter, only a fraction of the inhaled material is deposited in the lungs, the remainder is either exhaled or deposited in the upper respiratory passages and subsequently swallowed. The behavior of the material deposited in the lungs depends mainly on its solubility. Highly soluble materials are absorbed rapidly into the blood stream, perhaps in a matter of hours whereas insoluble material may persist in the lungs for many months. Clearly, then, the respiratory system represents a route of entry for radioactive substances i.e. (unstable nucleus disintegrating spontaneously) which can then be transported by the bloodstream to other parts of the body.

THE DIGESTIVE SYSTEMS:

Consists of the oesophagus, the stomach, the duodenum and the small intestine which is connected to the large intestine. Food taken in by the month is converted into a form suitable for the production of heat and energy, and the molecules necessary for the growth and repair of tissues. The large molecules in the food are broken down by enzymes in the digestive tract before being absorbed into blood stream and passed via the liver to the tissues. The unabsorbed food, together with bacteria and cells shed from the intestine wall out are passed out as solid waste (faeces). Liquid waste, (the waste products of cells dissolved in water) is excreted from the body via the kidneys and bladder as urine.

Soluble radioactive contamination, when swallowed, may pass through the digestive tract and become absorbed into the bloodstream which carried it to all parts of the body. Insoluble contamination passes through the digestive tract and is excreted in the faeces. During its passage through the body it will irradiate the tract and the large intestine.

CELL BIOLOGY

All living creatures and organisms consist of tiny structures known as cells. The basic components of cell are the nucleus, a surrounding liquid known as the cytoplasm and a membrane which forms the cell wall.

The cytoplasm breaks down food and converts it into energy and small molecules. These small molecules are later converted into complex molecules needed by the cell either for maintenance or duplication.

The nucleus contains the chromosomes which are tiny thread like structure made up of genes. Human cells normally contain 46 chromosomes. The genes consist of de-oxyribonucleic acid (DNA) and protein molecules and carry the information which determines the characteristics of the daughter cell.

Cells are able to reproduce to compensate for cells which die. Reproduction of cells occurs in two ways known as mitosis and meiosis. *The mitotic* cells are the ordinary cells in the body and in mitosis, the chromosomes duplicates by splitting lengthwise. The original cell then divides into two new cells each cells, each identical to the original cell.

Meiosis is a special kind of cell division which occurs during the formation of the sexual reproduction cells, namely the sperm in the male and the ovum in the female. It occurs only once in the cells life-cycle and only in the reproductive cells. In sexual reproduction a sperm and an ovum unit and the chromosomes combine to form a new cell containing genetic material (i.e. genes) from each of the parents. The embryo and subsequently the offspring develops from this single cell i.e the fertilized ovum.

INTERACTION OF RADIATION WITH CELLS

The basic difference between nuclear radiations and the more commonly encountered radiations such as heat and light is that the nuclear radiations have sufficient energy to cause ionization. In water of which cells are largely composed, ionization can lead to molecular changes and to the formation of chemical species of a type which are damaging to the chromosome material. The damage takes the form of changes in the construction and the function of the cell.

In the human body, these changes may manifest themselves as clinical symptoms such as radiation sickness, cataracts or, in the longer term cancer.

The processes leading to radiation damage are complex and are often considered in four stages:

i) The initial physical stage, lasting only a minute fraction (10^{-16}) of a second in which energy is deposited in the cell and causes ionization. In water the process may be written as:

$$H_2O \xrightarrow{\text{Radiation}} H_2O^{+} + e^{-}$$

Where H_2O^{+} is the positive ion and e^{-} the negative ion.

ii) The physico-chemical stage; lasting about 10^{-6} seconds in which the ions interact with other water molecules resulting in a number of new products. For example, the positive ion dissociates:

$$H_2O^{+} \longrightarrow H^{+} + OH^{-}$$

The negative ion, that is the election, attaches to a neutral water molecule which then dissociates:

$H_2O + e^{-} \longrightarrow H_2O^{-}$

$H_2O^{-} \longrightarrow H^{+} + OH^{-}$ thus the products of the reactions are H^{+}, OH^{-}, H and OH. These two products OH and H are called free radicals, that is they have an unpaired election and are chemically highly reactive.

iii) The chemical stage, lasting a few seconds in which the reaction products interact with the important organic molecules of the cell. The free radicals may attack the complex molecules which form the chromosomes. They may for example, attach themselves to a molecule or causes links in long chain molecules to be broken.

iv) The biological stage, in which the time scale varies from tens of minutes to tens of years depending on the particular symptoms.

The chemical; changes discussed above can affect an individual cell in a number of ways. e.g

(a) the early death of the cell,

(b) the prevention or delay of cell division, or

(c) a permanent modification which is passed on to daughter cells.

The effects of radiation on the human body are the results of damage to the individual cells. These effects may be conveniently divided into two classes, namely

1) Somatic effect
2) Hereditary effect

The somatic effects arise from damage to the ordinary cells of the body and affect only the irradiated person. The hereditary effects, on the other hand, are due to damage to the cells in the reproductive organ, the gonads. The important difference is that, in this case, the damage may be passed on to the person's children and subsequently to later generations.

THE SOMATIC EFFECT OF RADIATION

This effect is divided into the early radiation effects and the late effects.

THE EARLY RADIATION EFFECTS: are those which occur in the period from a few hours up to a few weeks after an acute exposure, which is a large dose, received over a few hours or less. The effects are due to major depletion of cell populations in a number of body organs due to cell-killing and the prevention or delay of cell-division. The main effects are attributable to bone-marrow, gastro-intestinal or neuromuscular damage depending on the dose received. (Absorbed dose is a measure of energy deposition in any medium by all type of ionizing radiation and its unit is the gray (Gy) and is defined as an energy deposition of 1J/kg).

Acute absorbed dose above about 1 gray gives rise to nausea and vomiting.

Absorbed doses above about 2Gy can lead to death, probably 10 to 15 days after exposure.

There is no well defined threshold dose below which there is no risk of death due to acute does, though below about 1.5Gy, the risk of early death would be very low. Similarly, there is no well defined point above which death is certain, but the chances of surviving an acute dose of about 8 Gy would be very low.

A reasonable estimate can be made of the dose which would be lethal for 50% of the exposed subject within 30 days of exposure. This is called the Ld_{50}^{30} and is thought to have a value of about 3 Gy for men.

For doses up to about 10Gy, death is usually due to secondary infections because of depletion of the white blood cells which normally provide protection against infection.

For doses above about 10Gy, survival time drops abruptly to between 3 – 5 days. The cells lining of the intestine are grossly damaged following severe bacterial invasion.

At much higher doses, survival time become progressively shorter. The symptoms indicate some damage to the Central Nervous System (CNS). Another effect which shows up after an acute over-exposure to radiation is erythema that is, reddening of the skin.

LATE EFFECTS: It became apparent in the early part of the twentieth century that groups of people such as radiologists and their patients, who were exposed to relatively high levels of radiation showed a higher incidence of certain types of cancer than groups not exposed to radiation.

The main effect due to late radiation effects is the cancer induction.

Cancer is an over-proliferation of cells in a body organ. It is thought that cancer may result from damage to the control system of a single cell, causing it to divide more rapidly than a normal cell. The defect being transmitted to the daughter cells so the population of abnormal cells builds up to the detriment of the normal cells in the organ.

The estimation of the increased risk of cancer is complicated by the long and variable latent period from about 5 to 30 years or more, between exposure and the appearance of the cancer. However at relatively high levels of exposure of e.g. people exposed to radiation from atomic bombs, patients exposed to radiation therapy, and of groups exposed occupationally, particularly uranium miners, approximate estimates can be made. The extrapolation of these estimates of the risk due to high doses to the much lower levels normally encountered in the nuclear industries or elsewhere introduces major uncertainties. The possibility cannot be ruled out that there is a threshold dose below which there is no risk of radiation induced cancer. However this is impossible to demonstrate and it is generally agreed that the only practicable basis for radiological protection is to assume that any dose, no matter how small, carries some risk examples of these cancer effects are the Leukaemia, the part of the body it affects is the red bone marrow, lung cancer – the lung, breast cancer – female breast, thyroid cancer – Thyroid, Liver cancer – Liver etc. Another possible late effect of radiation is cataracts formation in the lens of the eye. In this case it apears that there is a threshold dose, below which cataracts cannot be induced. This is of the order of 15Sv, so setting dose limits so that the total dose to the lens of the eye over the whole working lifetime is below this value, then possibility of cataract formation due to radiation can be avoided.

THE HEREDITARY EFFECTS OF RADIATION

This effect of radiation results from damage to the reproductive cells. This damage takes the form of alterations known as genetic mutations, in the hereditary material of the cell.

Radiation can induce gene mutations which are indistinguishable from naturally – occurring mutations. Since ionizing radiation can cause an increase in the mutation rate, it will increase the number of genetically abnormal people present in future generations. So strict control must be exercised over the radiation exposure of the general population.

The risks of hereditary effects due to exposure of the gonads are very uncertain. I.C.R.P (International Commission for Radiological protection estimated the risk of serious hereditary ill-health within the first two generations following the irradiation of either parent to be about 10 per million per milli sievert.

STOCHASTIC AND NON-STOCKASTIC EFFECT

Are terms recently introduced by ICRP to distinguish between effects for which probability of occurrence depends on the dose received and those for which the severity is related to dose.

The term stochastic can best be understood by considering it to refer to effects which either occur or do not occur, there being no intermediate state. Thus cancer – induction is a stochastic effect, the probability of a radiation – induced cancer of a particular type depends on the dose received. Hereditary effects are also regarded as being stochastic. The early effects of radiation are non-stochastic since their severity depends on the dose. Similarly, the severity of some late effects, such as cataracts formation, depends on the dose received and so these effects are also non-stochastic.

RADIATION PROTECTION, PRINCIPLES AND METHODS

Man has always been exposed to background radiation. This has two components:

Firstly, radiation from the radioactive substances in his surroundings and within his body, and secondly, cosmic radiation which reaches the earth from space. It was not until after the discovery of x-rays and radioactivity that the need for radiological protection as recognized. Early workers with x-rays and radioactive substances soon realized that radiations can cause harmful effects, since that time, a great deal of effort has been devoted to developing equipments, techniques and procedures to control radiation exposure.

Health physics is concerned with providing radiation protection for persons employed in radiation industries and for the population at large.

CARDINAL PRINCIPLES OF RADIATION PROTECTION

All health physics activity in radiology is designed to minimize exposure to patients and personnel. The three cardinal principles of radiation protection developed for nuclear activities find equal useful application in diagnostic radiology: i.e. time, distance and shielding. By observing the following principles, one can minimize radiation exposure:

1. Keep the time of exposure to radiation short.
2. Maintain a large distance between the source of radiation and the exposed person.
3. Insert shielding material between the source of radiation and the exposed person.

MINIMIZED TIME:

The dose accumulated by a person working in an area having a particular dose rate is directly proportional to the amount of time he spends in the area. His dose can thus be controlled by limiting the time he spends in the area: The equation for this relationship is

$$\text{Dose} = \text{dose rate} \times \text{time}$$

Example: The annual dose limit for category 'A' workers is 50mSv per year, assuming a 50 week working year, therefore corresponds to 1mSv, or 1000 µSv per week. How many hours could a worker spend each week in an area in which the dose rate is 50µSv/h?

Solution:

note: 1Gy = 1000 mGy = 1000000 µGy
1Sv = 1000 mSv = 1000000 µSv
1Sv = 100 rem, 1msv = 100 mrem

Dose = Dose rate x time

1000µSv = 50µSv/hr x time

$$\therefore t = \frac{1000\mu\text{Sv}}{50\mu\text{Sv/hr}}$$

t = 20hrs

Example 2: If a category A worker has to spend a full 40hrs working week in a particular area, what is the maximum dose rate which can be allowed?

Solution: Dose = dose rate x time

Since a 50 week working year is assumed and the dose limit for category A workers is 50 mSv per year which is equivalent to 1mSv per week (i.e. 1000µSv)

Then

Dose = dose rate x time

1000µsv = dose rate x 40hrs

∴ dose rate = 25µsv/hr

From these examples it can be seen that the dose rates which are of particular interest and which are commonly encountered in and around facilities such as nuclear reactors are in the range from about 1µSv/hr up to a few tens of µSv/hr. In some areas much higher dose rates may be encountered and, as the time to spend in an area is often dictated by the work to be done, some means of reducing the dose rate to personnel must be employed. The other available method is to increase the distance between the man and the source of radiation.

MAXIMIZED DISTANCE:

as the distance between the source of radiation and a person increases, the dose rate decreases rapidly. The decrease in dose rate can be calculated using the inverse square law if the source of radiation can be considered a point source, since the radiation dose is directly related to flux. Most radiation sources are point sources; the x-ray tube target, for example, is a point source of radiation. However, the scattered radiation generated within a patient appears to come not from a point but rather from an extended area. As a rule, even an extended source can be considered a point source **if** the distance from the source exceeds seven times the source diameter.

The inverse square law may be written as $D\alpha\frac{1}{r^2}\,or\quad D=\frac{K}{r^2}\therefore\quad D_1r_1^2=D_2r_2^2$ Where k is a constant for a particular source, D_1 is the dose rate at distance r_1 from the source and D_2 is the dose rate at distance r_2 from the source.

Example

The dose rate at 2m from a particular gamma source is 400 µSv/hr. At what distance will it give a dose rate of 25µSv/hr?

Solution: $D_1r_1^2=D_2r_2^2$

$$400\ \mu Sv/hr \times 2^2 = 25\ \mu Sv/hr \times r^2$$

$$\therefore\ r^2{}_2 = \frac{400\ \mu Sv/hr \times 4}{25\mu Sv/hr} = 64$$

$\therefore$ **r_2 = 8m**

It will be noted that doubling the distance from the source reduces the dose rate to one quarter of its original value, tripling the distance reduces the dose rate to one ninth, and so on.

A useful expression for calculating the approximate dose rate from a gamma source is

$$D = \frac{ME}{6r^2}$$

Where D is the dose rate in µSv/hr, M is the activity of the source in MBq , E is the gamma energy per disintegration, in MeV, and r is the distance from the source in metres. Care must be taken in selecting the correct units when applying this expression. It must be emphasized that in any real situation, protection should be based on measurements of the dose rate.

Example: calculate the approximate dose rate at a distance of 2m from a 240MBq Cobalt-60 source. Cobalt-60 emits two gamma rays per disintegration, of 1.17 and 1.33MeV.

$$D = \frac{ME}{6r^2} \quad \mu Sv/hr$$

$$= \frac{240 \times (1.17 + 1.33)}{6 \times 2^2} = \frac{240 \times 2.5}{24}$$

$$\mathbf{= 25\mu Sv/hr}$$

MAXIMIZED SHIELDING:

The third method of controlling the external radiation hazard is by means of shielding. Generally, this is the preferred method because it results into intrinsically safe working conditions, whilst reliance on distance or time of exposure may involve continuous administrative control over workers.

The amount of shielding required depends on the type of radiation, the activity of the source and on the dose rate which is acceptable outside the shielding material.

Alpha particles are very easily absorbed. A thin sheet of paper is usually sufficient to stop alpha particles and so they never present a shielding problem. Beta radiation is more penetrating than alpha radiation. In the energy range which is normally encountered

(1 – 10MeV) beta radiation requires shielding of up to 10mm of Perspex for complete absorption.

One important problem encountered when shielding against beta radiation concerns the emission of secondary x-rays, which result from the rapid slowing down of the beta particles. This x-radiation is known as **Bremstrahlung.** The fraction of beta energy reappearing as bremstrahlung is approximately ZE/3000 where Z is the atomic number of the absorber and E is the Beta energy in MeV. This means that beta shields should be constructed of materials of low mass number (e.g. aluminium or Perspex) to reduce the amount of bremstrahlung emitted.

Gamma and X-radiations:

They are attenuated exponentially when they pass through any material. The dose rate due to X– or γ-radiation emerging from a shield can be written as:

$$D_t = D_0 e^{-\mu t}$$

Where D_0 is the dose rate without shielding, D_t is the dose rate after passing through a shield of thickness t, and μ is the linear absorption coefficient of the material of the shield. The linear absorption coefficient μ is a function of the type of material used for the shield and also of the energy of the incident photons. Its dimension is $(\text{length})^{-1}$ and is usually expressed in m^{-1} or mm^{-1}.

Half-Value layer:

The half thickness or half value layer (HVL) for a particular shielding material is the thickness required to reduce the intensity to one half its incident value. Writing the half-value layer as $t_{½}$, the previous equation becomes;

$$\frac{Dt}{D_0} = 0.5 = \exp(-\mu t_{½})$$

Taking logs to base e:

$\text{Log}_e\, 0.5 = -\mu t_{½}$

$\therefore\ -0.693 = -\mu t_{½}$

$$\therefore\ t½ = \frac{0.693}{\mu}$$

The concept of HVL is very useful in doing rapid approximate shielding calculations. One HVL reduces the intensity to one half, two HVLs reduce the intensity to one quarter etc.

Example: The dose rate close to a valve is 160µSv/hr. If this is due to Cobalt-60 inside the valve, how much lead shielding placed around the valve to reduce the dose rate to 10µSv/hr? HVL of lead for 60-C_0 gamma radiation is 12.5mm.

Solution:

It is required to reduce the dose rate from 160µSv/h to 10µSv/h, i.e. by a factor of 16. To do this will require 4 HVL of lead, therefore 4 x 12.5mm of lead are required.

MAXIMUM PERMISSIBLE DOSES

For practical purposes, it is desirable to determine the maximum doses of radiation which can be assumed to constitute a negligible hazard to people. The international commission on radiological protection has therefore defined a permissible dose for an individual.

DEFINITION: a permissible dose is that dose, accumulated over a long period of time or resulting from a single exposure, which, in the light of present knowledge, carries a negligible probability of severe somatic or genetic injuries. Furthermore, it is such a dose that any effects which ensure more frequently are limited to those of a minor nature that would not be considered unacceptable by the exposed individual or by competent medical authorities.

Also, when considering the general public, i.e. a large number of people compared to the relatively small number of individuals who are radiation workers, the doses must be further limited so that they do not result in an unacceptable burden of genetic changes in future generations. On this basis, the code of practice gives values for the maximum permissible doses for radiation workers and for other persons.

The aim of radiation protection, as stated by ICRP, is achieved by:

a) setting dose equivalent limits at levels which are sufficiently low to ensure that no threshold dose is reached, even following exposure for the whole of an individual’s life-time – prevention of non-stochastic effects; and
b) keeping all justifiable exposures as low as is reasonably achievable, economic and social factors being taken into account, subject always to the boundary condition that the appropriate dose equivalent limits shall not be exceeded – limitation of stochastic effects.

RECOMMENDED DOSE EQUIVALENT LIMITS FOR WORKERS

To prevent non-stochastic effects, a dose equivalent limit of 0.5Sv (50 rem) in a year is recommended for all tissues except the lens of the eye, for which a lower limit of 0.3Sv (30 rem) in a year is recommended.

To limit stochastic effects, the annual dose equivalent limit for uniform irradiation of the while body is set at 50msv (5 rem). For non-uniform irradiation of the body, weighting factors have been assigned to the various individual organs, relative to the whole body as 1.0, reflecting the harm attributable to irradiation of each organ. The equation relating the annual dose equivalents in an individual tissues with that of the whole body is:

$$\sum W_T H_T \leq H_{Wb,L}$$

Where W_T is the weighting factor for tissue T, H_T is the annual dose equivalent in tissue T, and $H_{wb,L}$ is the recommended annual dose equivalent limit for uniform irradiation of the whole body. In the limit the above equation becomes

$$\sum_T W_T H_T = \quad 50mSv(5rem)$$

Table 1: The weighting factors are given in the table below

Tissues	**W_T**
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lungs	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30
	1.00 → whole body

Example: Calculate the allowable dose equivalent to the thyroid of a worker for a year in which he is exposed to non-uniform irradiation involving the whole body and the lung, as well as the thyroid. During the year he receives dose equivalents of 25mSv (2.5 rem) to the whole body and 150mSv (15 rem) to the lung.

Solution: Using the weighting factor formula

W(whole body) x H(whole body) + W(lung) x H(lung) + W(Thyroid) x H (thyroid) $\leq$ 50mSv (5 rem).

1.0 x 25mSv + 0.12 x 150mSv + 0.03 x H (Thyroid) = 50mSv, in the limit.

i.e 25mSv + 18 mSv + 0.33x H(Thyroid) = 50mSv

$$H(\text{Thyroid}) = \frac{50 - 43}{0.03} = 223\text{mSv}$$

Thus, the worker is permitted to receive up to 233msv (23.3 rem) dose equivalent to the thyroid during the year in question.

Example 2: using the weighting factors above. Calculate the implied limits for each of the following organs, assuming that each organ is irradiated completely in isolation: the gonads, the thyroid, the bone surfaces.

Solution:

For gonads, $W_T = 0.25$ and so, implied annual limit = $\frac{50}{0.25}$ = 200 mSv (20rem)

For thyroid, $W_T = 0.03$, thus implied annual limit = $\frac{50}{0.03}$ = 1670 mSv (167rem)

For bone surfaces, $W_T = 0.03$ and so, implied annual limit = $\frac{50}{0.03}$ = 1670 mSv (167rem).

Note: The above limits are based on stochastic effects. For all organs and tissues there is an additional limitation, based on non-stochastic effects, which prohibits any organ or tissue receiving an annual dose equivalent greater than 500 mSv (50 rem), or 300 mSv, (30 rem) for lens of eye.

ICRP defines two conditions of work:

1. working condition A
2. working condition B

For working condition A; where annual exposures might exceed 3/10 of the dose equivalent limits individual monitoring and pre-operational medical examination is required.

For working condition B: where annual exposures are unlikely to exceed 3/10 of the dose equivalent limits, individual monitoring and pre-operational medical examination is not necessary.

RECOMMENDED DOSE EQUIVALENT LIMITS FOR INDIVIDUAL MEMBERS OF THE PUBLIC

To prevent non-stochastic effects, a dose equivalent limit of 50 mSv (5 rem) in a year is recommended for all tissues.

To limit stochastic effects, the annual equivalent limit for uniform irradiation of the whole body is set at 5mSv (0.5 rem). For non-uniform irradiation of the body the same formula and weighting factors are used as were given in the above table for workers. The genetic dose limit of 50 mSv (5 rem) in 30 years is proposed.

The above maximum permissible doses do not apply to patients because the benefits of a particular radiation procedure will probably far outweigh the small risk involved. It is nevertheless desirable to limit the exposure of patients to the minimum value constituent with the medical requirements.

TYPES OF EXPOSURE:

In radiation, we are concerned with two types of exposures:

i) a single accidental exposure of high dose is referred to as acute exposure and which may produce biological effects within a short time after exposure.

ii) Long-term, low level over exposure, commonly called continuous or chronic exposure, where the results of the overexposure may not be apparent for years, and which is likely to be the result of improper or inadequate protective measures.

Acute radiation exposure is a highly dramatic but also exceedingly rare event, induced by exposure of the whole body to a very high penetrating radiation.

Excluding wartime casualties, such accidental overexposures have affected less than 150 people throughout the world. About half of these cases arose during operations in the nuclear industry, the others being due to exposure to radioisotopes and x-ray sources. The clinical effects in such accidents are dependent upon:

1) Time during which the exposure took place and dose rate.
2) Total accumulated dose and
3) The nature of the radiation

Acute whole body over exposure affect all organs and systems of the body, the sensitivity of the body differ from parts to parts hence degree of disease syndrome depends on magnitude of dose. Acute radiation syndrome is one of the examples of non-stochastic effects.

ACUTE RADIATION SYNDROME (ARS): is an acute illness caused by irradiation of the whole body (or a significant portion of it). It follows a somewhat predictable course and is characterized by signs and symptoms which are manifestations of cellular deficiencies and the reactions of various cells, tissues, organ and systems to ionizing radiation.

Immediate, overt manifestations of the acute radiation syndrome require a large (i.e., hundreds of rem, usually whole body) dose of penetrating radiation delivered over a short period of time. Penetrating radiation comes from a radioactive source or machine that emits gamma rays, x-rays, or neutrons.

The ARS is characterized by four distinct phases: a prodromal period, a latent period, a period of illness, and one of recovery or death. During the prodomal period patients might experience loss of appetite, nausea, vomiting fatigue, and diarrhea; after extremely high doses, additional symptoms such as fever, respiratory distress, and hyperexcitability can occur. However, all of these symptoms usually disappear in a day or two and a symptom – free, latent period follows, varying in length depending upon the size of the radiation dose. A period of overt illness follows, and can be characterized by infection, electrolyte imbalance, diarrhea, bleeding, cardiovascular collapse and sometimes short periods of unconsciousness. Death or a period of recovery follows the period of overt illness.

In general, the higher the dose the greater the severity of early and the greater the possibility of late effects. Depending on the dose, the following syndromes can manifest:

- **Dose less than 2Gy (200 rads)**

Nausea and vomiting due to radiation are seldom (rarely, occasionally) experienced unless the exposure has been at least 0.75 to 1Gy (75 – 100 rads) of penetrating gamma or X-rays and it occurs within a matter of a few hours or less. Hospitalization generally will be unnecessary if the dose has been less than 2Gy (200 rads).

- **Acute radiation syndrome: Dose greater than 2Gy**

Signs and symptoms become increasingly severe with dose;

Hematopoietic syndrome: characterized by deficiencies of white blood cell, lymphocytes and platlets.

- **The prodromal phase:** nausea and vomiting within a few hours at the higher dose levels, or after 6 to 12 hours at the lower dose levels. Lasts 24 to 48 hours, after which the patient is asymptomatic and may feel well. The absolute lymphocyte count will fall, a stress response of WBC may be present.
- **The latent phase:** lasts a few days to as long as 2 to 3 weeks at the lower dose levels. The patient is asymptomatic but will show characteristic change in the

blood elements, with lymphocyte depression and gradual decrease in platlet counts.

- **A bone marrow depression phase** requires sophisticated treatment. Infection and hemorrhage could occur when white cell and platelet counts become critically low.
- **The recovery phase:** stem cells in the bone marrow are never completely eradicated at 2 to 10Gy.

GASTROINTESTINAL SYNDROME (OVER 10 Gy): Characterized by loss of cells lining the intestinal crypts. This syndrome is distinguishable from the hematopoietic syndrome by the immediate, prompt and profuse onset of nausea, vomiting and diarrhea, followed by a short latent period. Gastrointestinal symptoms recur and lead to alteration in the intestinal motility, fluid and electrolyte loss leading to dehydration, loss of normal intestinal bacteria and damage to the intestinal microcirculation. If the patient survives long enough, depression of the hematopoietic system occurs and complicates the clinical course.

CEREBROVASCULAR (Cardiovascular) /CENTRAL NERVOUS SYSTEM SYNDROME (over 30Gy): Primarily associated with effects on the vasculature and resultant fluid shifts. This is an extremely high dose, to the whole-body. Always fatal, there is immediate nausea, vomiting, confusion, disorientation, and irreversible hypotension; blood pressure will be markedly unstable. Within hours after exposure, the victim will be drowsy, convulsive. Death most likely will occur within a matter of days.

SKIN SYNDROME: Can occur with other syndrome; characterized by loss of epidermis (and possibly dermis) with ‘radiation burns’.

USES OF RADIATION – INDUSTRIAL USES

Is it true that radioactivity can be found in the industry? Yes, there are wide-spread uses of radiation and radioactivity in industrial operations.

Well, we shall take advantage of the following four characteristics of radiation sources for industrial uses: That radiation affects materials; that materials affect radiation; that radiation traces materials; and that radiation produces heat and power in a variety of industries.

How does the fact that radiation affects materials make it useful in industry? Radiation affects, to various degrees, any material that is exposed to it. As a result, applications such as pasteurization (preservation), and sterilization of food, polymerization of organic compounds, sterilization of medical supplies, and elimination of static electricity are possible.

How is the fact that materials affect radiation useful in the industries? The intensity of nuclear radiation is reduced by thicker or denser materials that are in the path of the radiation. This is the characteristic that is responsible for such applications as radiographs (i.e. taking pictures through objects), locating or controlling hidden levels of solids and liquids, which is especially helpful if the liquid, is hot, corrosive or under pressure, and determining the thickness of materials.

How does radiation “traces” materials? Radioactive elements and stable elements have identical radioactive chemical behaviors. However, radioactive elements are able to “announce” their presence through the radiations that are given off. So, not only do the radioactive elements take part in the same reaction or process as the stable elements, but they continually show their exact location by the “signals’ they give off. All that is needed is some sort of device to detect their presence. Our ability to trace the location of radioactive elements permits us to test wear, to locate leaks, to trace fluid flow, to evaluate detergent efficiency, and a host of other operations.

How true is the statement that radiation produces heat and power? Whenever an energetic particle or ray is slowed down or stopped, heat is given off. We can take advantage of these characteristics by converting the heat produced to electrical or mechanical energy, or simply using it directly. Among the applications that use this characteristic are electrical generators for unmanned weather stations and power devices for thrusters in the space program, and heat for diving suits.

SPECIFIC USES OF RADIOACTIVITY IN INDUSTRY

1. APPLICATION IN THE METAL INDUSTRIES

a) For tracing: In blast furnace operations, radioactivity is used to study i.e. (trace) the residence time and distribution of constituents in the various metallurgical processes. Other tracer studies compare methods of chemically cleaning copper and stainless steel parts, evaluating plating techniques, and adding to our knowledge of the structure of electroplated coatings.

Radionuclides have also been used to evaluate the diffusion of gases into metals (causing brittleness), and they have been used to provide valuable information on the rate of tool wear.

b) For gauging: using radioactivity to gauge thickness has been well-recognized by industry. It permits us to impose continuous control of the uniformity of the thickness of various kinds of sheets and layers to very close tolerances. Furthermore, these types of systems can be completely automated so that the response to thickness changes can be used to actuate rollers, thus providing closer control than would otherwise be possible.

In addition to thickness, we can also use radioactivity to gauge the density of various materials.

The density of a variety of liquid powders, and granular solids can be measured by having a radiation source and a detector mounted on opposite sides of the material being measured (i.e. like in a pipeline). If the detected intensity of radiation from the source increases or decreases, we know that the density of the material has decreased or increased respectively.

c) **The use of radioactive cobalt for flaw detection** in masses of metal was one of the earliest applications of radionuclide radiography. Most operations maintain a selection of radiation sources, including radioactive cobalt, iridium and cesium etc.

2) APPLICATION IN THE ELECTRICAL INDUSTRY

One example is the use of radioactive krypton gas for leak testing. This procedure involves exposing electronic components to the gas under pressure for some period of time, during which any leaky components are at least partially filed with the gas. After the exposure period, the surface of the components is cleaned and the leaky components are quickly identified by detecting the residual radioactivity.

For tracing: They are used to study adsorption and desorption of mercury by glass surfaces in mercury switches, evaluation of method for cleaning metal surfaces prior to electroplating or enameling, wear testing of bearings, determination of lubrication and seal characteristics, and improving the mechanisms of the diffusion.

Gauging in electrical industry is limited. We don’t typically see many application here.

In radiography: there are some uses here. Radiation sources are used to check the integrity of welds on structural components of heavy industrial electrical equipment.

Radiation sources are also used for static elimination, in fire detection equipment, and in luminous dials, gauges and signs. Certain investigational lights also contain radioactivity. In addition, there has been considerable interest in the use of radionuclides to replace batteries and related power sources.

3) APPLICATIONS IN THE CHEMICAL INDUSTRY

Refineries pump a lot of fluids, including raw materials and other in-plant inventory and products. Radiation source are used as part of the automatic (computerized) control of the flow of these fluids. They also let the operators know if a blockage occurs! However, by far, the most extensive use of radionuclides in this and other chemical industries is as a tracer.

How is radioactivity used in chemical processing?

There are many types of radiation sources used in this industry. For example, radioactive sulphur can be used to determine the efficiency of separation; radioactive gold and iodine can be used to determine the thoroughness of mixing; radioactive sodium and bromine are used for locating leaks, and radioactive cobalt and cesium are used for gauging liquid or solid levels. Other radiation sources might be used to study and process stream flow patterns, locate pipe obstructions, study mass balances in refinery streams, measure flow velocities, study catalysts movement, study carbon deposits in fuel research for drug metabolism studies, determine tire wear, study diffusion in glass, eliminate static, and sterilize medical supplies etc.

Few ways in which radioactivity is used in our consumer product industry

I don’t mean radioactivity that is incorporated into products themselves, I mean how radioactivity is used to improve the products that we use and take for granted.

Radioactivity is sometimes used for determining the rate of wear in floor wax. It can also be used to assess laundering efficiencies of various detergents. Radioactivity has been used to determine the firmness of cigarette, the rate of pesticides removal from surfaces, the metabolism of food additives, biosynthesis, the movement of textile layers, the control of solid and liquid levels of foods and beverages in their containers, sterilization and pasteurization of food, and even the migration of dyes in the printing business.

In the case of industry, radiation and radioactivity are definitely beneficial.

USES OF RADIATION – MEDICAL USES

Radiation is playing an increasingly important role in the diagnosis and treatment of various diseases.

Uses include the following;

X-rays: one of the common uses of machine generated radiation in medicine is the X-ray. Although more damaging to biological tissue than visible light due to the fact that the associated photons have more energy, X-rays can see finer detail when used in a "microscope" due to their short wavelength to identify diseases and diagnose injuries.

As X-rays pass through the body, they are absorbed by various tissues according to the density of the tissues. X-ray pass through soft tissue easily, but less easily through bone. The X-ray film is placed behind the body. It is blackened according to how many X-rays reach it. Bones show up as lighter areas because they absorb the X-rays and prevent most of them from passing through the bone to the film.

In the days before the dangers of X-rays were appreciated, they were used as a novelty in some shoe stores to accurately determine the foot size. In a CAT scan (Computer Assisted Tomography), X- rays are taken form a variety of angles, and the individual slices are then fed into a computer to reconstruct a 3-dimensional image of the object under study.

Tumor treatment: Radiation is used to destroy tumors present in a body. Damage to healthy cells is controlled by using radioactive samples with specific half-lives which subsequently are intended to decay in the vicinity of the tumor when injected into the body.

Tracer techniques: Another use of radiation is in the tracer techniques; the body absorbs various elements but does not discriminate between different isotopes. In tracer techniques a radioactive isotope (radioisotopes are isotopes that give off radiation), of such an element, as iodine, is injected into the body. The signals coming from the ensuring radiation then give a picture of the size and location of the area where the isotope was absorbed. Usually isotopes of a relativity short half-life, of the order of minutes or days, are used to minimize long term radiation damage.

PET Scans: is another way through which radiation is used in medicine. PET (Position Emission Tomography) scans involves the injection into the body of an isotope which decays by position emission. When this position encounters an electron they annihilate each other, emitting two photons i.e (their masses combined and are completely destroyed i.e. their mass are converted into 1.02 MeV of energy. This energy is radiated as two photons each of energy 0.51MeV, traveling at 180^o to each other). The energy and path of these photons leaving the body can be used to give an accurate picture of the area where the isotope was absorbed.

Table 2: Some example of artificial radionuclides used in medicine

Radionuclide	**Half-life**	**Particle emitted**	**Uses**
$^{3}_{1}H$	12.3y	β^-	Tracer studies
$^{14}_{6}C$	5760y	β^-	Tracer studies
$^{22}_{11}Na$	2.6y	B^+, E.C*	Tracer studies
$^{24}_{11}Na$	15.0 hrs	β^-	Tracer studies
$^{32}_{15}P$	14.3 day	β^-	Therapy and Tracer studies
$^{35}_{16}S$	87.2 d	β^-	Tracer studies
$^{45}_{20}CA$	165 d	β^-	Tracers for bone studies and other calcium metabolism studies.
$^{47}_{20}CA$	4.7 d	β^-	
$^{51}_{24}Cr$	27.8 d	E.C*	Tracers for blood studies.
$^{59}_{26}Fe$	45 d	β^-	
$^{58}_{27}Co$	71 day	β^-	Tracer for anaemia studies teletherapy units and therapy sources.
$^{60}_{27}Co$	5.26 y	β^-	
$^{131}_{53}I$	8.04 d	β^-	Therapy and tracer for thyroid studies.
$^{132}_{53}I$	2.3 hrs	β^-	
$^{137}_{55}CS$	30 yrs	β^-	Teletherapy units
$^{198}_{79}Au$	2.7 d	β^-	Therapy
$^{197}_{80}Hg$	65 h	E.C*	Tracer for kidney studies

The advantages of these and other uses of radiation must be balanced against the health risks. As well, less dangerous diagnostic devices are being actively developed. One obvious one is the use of ultrasound for fetal monitoring, which because it involves sound waves is far less dangerous than x-rays. Another technique is MRI (Magnetic Resonance Imaging), which formerly was known as NMR (Nuclear Magnetic Resonance). This technique exploits the fact that the nucleus has certain magnetic properties due to the spin of the nucleons, much like an atom has magnetic properties due to the orbiting electrons. When subjected to a relatively large magnetic field, and subsequently probed with particular waves, these nuclei respond by emitting characteristic waves. These waves are not dangerous, are then tracked, and their properties are used to construct an image of the area being probed. So radiation is used in many aspects of medicine. Some uses are more obvious than others.

Non-Medical uses: some of the ways radiation is used in non-medical settings include the following:

Carbon dating: Every living thing absorbs carbon, including the relatively rare isotope ^{14}C (about 1% of all carbon isotopes). Carbon-14 is radioactive by beta- emission, with a half-life of about 5700 years. When the specimen dies, it stops absorbing carbon, and so by measuring the amount of ^{14}C present in a sample, and comparing with a comparable living specimen, one can get an estimate of the sample's age.

Sterilization of equipment and food: The fact that radiation can destroy biological material is used in the sterilization of medical equipment, where a lack of contamination is essential. More controversial is the same use on food, where it is used to destroy agents which hasten spoilage.

Smoke detectors: in a smoke detector, a low-level radioactive material is present. This radiation can ionize particles contained in smoke, which are subsequently detected by their charge.

PERSONNEL RADIATION MONITORING

Radiologists and X-ray technologists are routinely exposed to ionizing radiation. The level of exposure is dependent upon the type of activity in which they are engaged and how much of it they do. Determining the quantity of radiation they receive requires a program of personnel monitoring.

Personnel monitoring refers to procedures instituted to estimate the amount of radiation received by individuals who work around radiation. The personnel monitor offers no protection against radiation exposure. It simply measures the quantity of radiation to which it was exposed and therefore is used as an indicator of the exposure of the wearer. There are basically three types of personnel monitors use in diagnostic radiology.

i. Film badge
ii. Thermo luminescent dosimeters (TLD and
iii. Pocket ionization chamber – the sequence of events that must be undergone before using Pocket ionization chambers can be time – consuming, they are not employed frequently in diagnostic radiology, so we shall only discuss in detail, the remaining two.

FILM BADGES: They came into general use about the mid – 1940s and have been widely employed in diagnostic radiology ever since. Film badges are specially designed devices in which a small piece of film similar to dental radiographic film is sandwitched between metal filters inside a plastic holder, as shown in figure 2, below.

Fig 2: Film Badges

The film incorporated into a film badge is a special radiation – dosimetry film that is particularly sensitive to ionizing radiation. The density on the exposed and processed film is proportional to the exposure received by the film badge. Carefully controlled calibration, processing, and analyzing conditions are necessary for the film badge to accurately measure occupational exposure. Usually, exposures less than 20 mRad are not measured by film – badge monitors, and the film badge vendor will report only that a minimal exposure (M) was received. When higher exposures are received, they can be accurately reported.

The metal filter along the window in the plastic film badge allows estimation of the radiation energy. The usual filters are made of aluminium and copper. If the radiation exposure is due to penetrating radiation, the image of the filters on the processed film will be faint and there may be no image at all of the widow in the plastic holder. If the badge in exposed to soft radiation, the filters will be well imaged and the density under the filters will allow estimation of the X-ray energy. Often the filters to the front of the badge and from the filters to the back of the badge have different shapes to allow the film – badge vendor to determine, if the radiation detected by the badge entered through the front or the back of the badge. Radiation that had entered through the back of badge would normally indicate that the person wearing the badge was exposed to considerably higher levels of radiation than indicated, since the radiation would have penetrated through the body before interacting with the film badge. For this reason, film badges must be worn with their proper side to the front.

Several advantages of film-badge personnel monitors continue to make them popular. They are inexpensive, easy to handle, not difficult to process, reasonably accurate and have been in use for several decades. A film badge provides permanent record with an indication of the type and energy of the radiation involve. Film-badge monitors also have disadvantages since they incorporate film as the sensing device, they cannot be worn for long periods of time because of fogging due to temperature and humidity.

Film-badge monitors should never be left in an enclosed car or other areas where excessive temperatures may occur. The fogging produced by elevated temperature and humidity will result in a false high elevation of exposure. Consequently, film-badge monitors should not be worn for longer than 1 month. Film-badge monitors do not have the sensitivity of other personnel monitoring devices.

THERMOLUMINESCENT DOSIMETERS (TLDs)

TLDs are relatively new type of personnel monitoring device. The sensing material of the TLD monitor is lithium fluoride (LiF) in **crystalline form**, either as a powder or, more often, as a small chip approximately 3mm square and 1mm thick. When exposed to radiation, the TLD absorbs energy and stores it in the form of excited electrons in the crystalline lattice.

If heated, these excited electrons fall back to the normal orbital state with the emission of visible light. The intensity of the visible light is measured with a photomultiplier tube and is proportional to the radiation dose received by the crystal. A typical TLD personnel monitor is shown in figure 3, below.

Fig 3: The thermoluminescence (TLD) badges

TLD monitoring devices have several advantages over film. They are more sensitive and more accurate than film-badge monitors. Properly calibrated TLD monitors can measure exposures as low as 5mR. TLD monitors do not suffer from loss of information following exposure to excessive heat or humidity consequently, they can be worn for intervals up to 3 months at a time. The primary disadvantage of TLD personnel monitoring is cost. The price of a typical TLD monitoring service is perhaps twice that of film-badge monitoring. If the frequency of monitoring is quarterly, however, the price differential becomes less important. TLD has the additional advantage of simplicity. Some departments of radiology process their own TLD personnel monitors. This is not so easy with film badges. Unlike the film-badge which provides a permanent record of exposure, the information stored on a TLD powder can be read out only once and no permanent record remains. TLD monitoring is improving constantly and is slowly replacing film-badge monitoring. Within the next decade, the use of film-badge personnel monitors may cease entirely.