

2.1 NATURE OF RADIATION & UNITS OF MEASUREMENT

2.1.0 Introduction

For the purposes of this manual, we can use a simplistic model of an atom. The atom can be thought of as a system containing a positively charged nucleus and negatively charged electrons in orbit around the nucleus.

All matter is composed of elements and all elements are composed of atoms. While it may appear that the atom is the basic building block of nature, the simplified, classical (Bohr's concept) model of the atom itself is composed of three smaller, more fundamental particles called protons, neutrons and electrons.

Each atom has the same number of protons as it has electrons. This means that the total positive charge in the nucleus is equal to the total negative charge of the electrons and resulting in an electrically neutral atom. Each element has a unique number of protons and electrons.

For each element, every individual arrangement of protons and neutrons is called a nuclide. All the atoms of a particular element contain the same number of protons. However, the number of neutrons may vary for the same element.

The nucleus is the central core of the atom and is composed of two types of particles, protons, which are positively charged, and neutrons, which have a neutral charge. Each of these particles has a mass of approximately one atomic mass unit (amu). (1 amu = $1.66E^{-24}$ g).

Electrons surround the nucleus in orbitals of various energies. (In simple terms, the farther an electron is from the nucleus, the less energy is required to free it from the atom.) Electrons are very light compared to protons and neutrons. Each electron has a mass of approximately $5.5E^{-4}$ amu.

A nuclide is an atom described by its atomic number (Z) and its mass number (A). The Z number is equal to the charge (number of protons) in the nucleus, which is a characteristic of the element. The A number is equal to the total number of protons and neutrons in the nucleus.

These different nuclear forms of an element are called isotopes, that is, an atom with the same number of protons but different numbers of neutrons. For example, phosphorous has seven different isotopes. Each of the isotopes has 15 protons, while the number of neutrons varies from 28 to 34.

Many nuclides are unstable because the ratio of neutrons to protons produces a nuclear imbalance (that is, too many protons or too many neutrons in the nucleus). These unstable isotopes attempt to become stable by rearranging the number of protons and neutrons in the nucleus to achieve a more stable ratio. The excess energy is ejected from the nucleus as radiation.

In this rearrangement process, the isotope often changes atomic number (for instance, a

neutron changes into a proton and an electron, or a proton captures an electron and becomes a neutron) and sheds any excess energy by emitting secondary particles and/or electromagnetic rays (or photons). This change in the nucleus is called nuclear disintegration. The process of unstable isotopes disintegrating and emitting energy is called radioactive decay. An isotope undergoing radioactive decay is said to be radioactive.

This process of nuclear disintegration can be one of four different types:

- Alpha radiation
- Beta Radiation
- Gamma Radiation (including X-rays)
- Neutrons (both fast and thermal).

These forms of radiation have sufficient energy to cause atomic changes (that is ionisation) on interaction. An ion is an electrically charged atom, group or molecule formed by the loss or gain of one or more electrons. Ionisation is the process of separation or change into ions.

2.1.1 Radiation as the Transport of Energy

Radiation is often loosely described as the transport of energy. Unfortunately this description includes phenomena that are not generally regarded as 'radiation', (such as heat flow in a metal rod by conduction). In cases where the energy is either electromagnetic in nature, or alternatively the kinetic energy of sub-atomic particles, then the description becomes more useful. It is also useful in cases where mechanical energy is transported by a wave mechanism (sound).

Since it is the ultimate transfer of this energy into biological tissue that is a concern in terms of any subsequent biological effect, various measures of radiation can be conceived relating to both energy transport and energy transfer.

2.1.2 Ionizing Radiation (IR) vs Non Ionizing Radiation (NIR)

Radiation is often classified into ionizing and non-ionizing. This refers to the ability of the radiation to ionize atoms. Of special importance are those atoms found in biological molecules. Other materials include air and various gases used in radiation detectors (that is: ionizing radiation is detected and identified if measurable ionisation occurs). Ionizing radiation is associated with the prefix '*radio-*' for historical reasons. Thus, there is '*radiological* protection', which is concerned with protective measures against ionizing radiation. Radiological protection is a subset of radiation protection, the latter being concerned with hazards in regard to *all* radiation types and energies.

Ionizing radiations are of special concern because the ability to ionize biological atoms (which are aggregated in larger molecular forms) implies a definite ability to cause changes at the molecular level. Ionisation of an atom requires well defined localization of energy that can transfer some or all of the energy to an atomic electron. High frequency electromagnetic radiation can be effectively regarded as the motion (at light speed) of individual quanta, or photons, whereby each photons energy, E , is proportional

to the classical 'wave frequency', f : $E = hf$ and where the proportionality constant h is known as Plancks constant.

Whilst ionisation is important as a mechanism for damage, the energy transferred from the radiation to the atoms of the irradiated material can also manifest in the form of *excited* atoms. This refers to a condition in which at least one electron in an atom is raised in its potential energy level due to absorption of some or all of the original photon energy. This can happen with not only particles and photons of ionizing radiation energy values, but also photons with somewhat lower energy levels.

2.1.3 Radiation Types

Following is a short description of the four types:

Alpha radiation is particulate radiation with a very large mass (atomic mass of 4) but it does not penetrate material (including air) very deeply. The mass means that this radiation can impart a large energy to material. Generally a sheet of ordinary paper is sufficient to act as a shield from external radiation.

Beta radiation is equivalent to an electron. It has the mass of an electron (which is negligible) and can exhibit the characteristics of both particles and electromagnetic waves. Beta particles travel at greater speeds than Alpha particles and can penetrate to reasonable distances (e.g. ^{32}P can travel approximately 6 metres in air, but only about 1mm in mammalian tissue). Beta radiation has another problem during the interaction with high Z (atomic number) materials such as lead or steel. During this interaction the beta particle is dramatically slowed and the energy is lost as X-rays (gamma rays) and is termed bremsstrahlung, with energies ranging up to the peak energy of the interacting beta. This is why Perspex (of appropriate thickness) is used for shielding.

Gamma rays (and X-rays) are electromagnetic waves from nuclear reactions. These waves travel at the speed of light and may penetrate to infinity (depending on a number of factors). High Z materials of appropriate thickness are the recommended shielding. As they are unlike alpha and beta radiations, i.e. they are not particulate, these waves can pass through the interstitial spaces of mammalian tissue without causing disruption. However having said that, in passing through sufficient thickness of living tissue the possibility of interaction and thus ionisation greatly increases.

Neutrons these are one of the sub-atomic particles and are usually found only from nuclear reactions and a few specialist items of equipment such as bore hole loggers. Because they have mass and also a great velocity this radiation can impart great energy when they interact with matter and very easily cause ionisation. Care and good shielding are required for these radiations.

2.1.4 Radiation Decay/Half-life

The decay of a radioactive sample is statistical in nature and it is impossible to predict when any particular atom will disintegrate. The result of this random behaviour of any particular atom is that the radioactive decay law is exponential in nature, and is expressed mathematically as:

$$N = N_0 e^{-\lambda t}$$

Where N_0 is the number of nuclei present initially, N is the number of nuclei present at time t and λ is the radioactive decay constant.

The *half-life* ($T_{1/2}$) of a radioactive species is the time required for one half of the nuclei in a sample to decay. It is obtained by putting $N = N_0/2$ in the above equation:

$$N_0/2 = N_0 e^{-\lambda T_{1/2}}$$

Dividing across by N_0 and taking logs

$$\log_e(1/2) = -\lambda T_{1/2}$$

Now

$$\log_e(1/2) = -\log_e(2)$$

and so

$$T_{1/2} = (\log_e(2))/\lambda = 0.693/\lambda$$

Since the disintegration rate, or *activity* of the sample is proportional to the number of unstable nuclei, this also varies exponentially with time, namely:

$$A = A_0 e^{-\lambda t}$$

This relationship is illustrated in Fig. 1 (real isotope example in figure 2) which shows the variation of sample activity with time. In one half-life the activity decays to $1/2 A_0$, in two half-lives to $1/4 A_0$, and so on. The half-life of a particular radioactive isotope is constant and its measurement assists in the identification of radioactive samples of unknown composition. This method can only be applied to isotopes whose disintegration rates change appreciably over reasonable counting periods. At the other end of the scale, the isotope must have a long enough half-life to allow some measurements to be made before it all disintegrates.

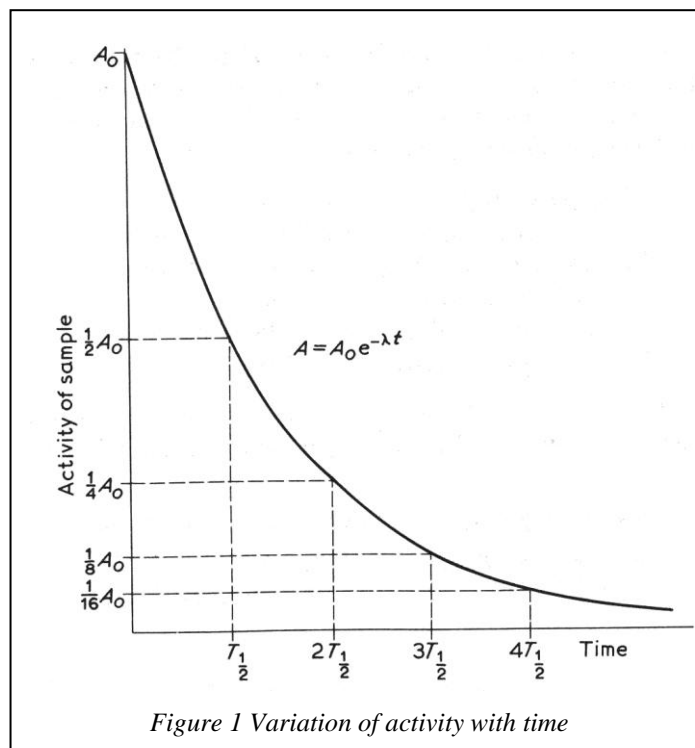
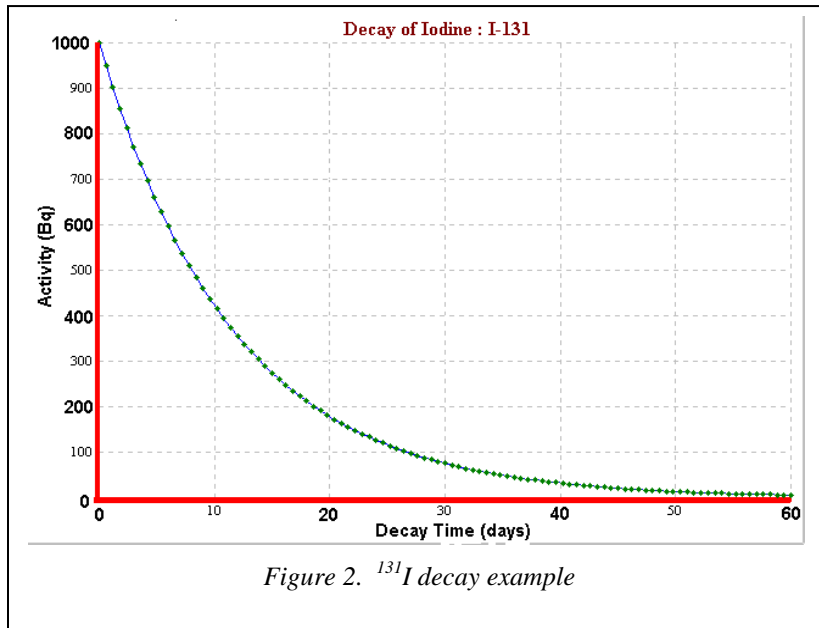


Figure 1 Variation of activity with time



Typically, the result of radioactive decay gives rise to gamma γ radiation (photons), Beta particles (electrons), positrons (Beta-plus β^+ radiation) or Alpha particles (two protons and two neutrons, the same as helium nuclei). It is also possible for a radioactive material to emit more than one form of radiation on decay, for example Ag-108 produces possibly (allowing for the probability of occurrence) 9 photons and 2 betas on decay.

2.1.5 Radiation Units and Quantities

In Australia we use the SI units. The units that are legally required to be used in Australia are:

- Activity is the **Becquerel**
- Exposure is the **Coulomb/Kg**
- Absorbed dose is the **Gray**
- Dose Equivalent is the **Sievert**
- Effective dose is the **Sievert**

The Becquerel is defined as one disintegration per second.

The fundamental quantity in radiation protection is the **absorbed dose**. Absorbed dose is a measurement of energy deposition in any medium by any type of ionizing radiation.

The SI unit of absorbed dose is the **Gray (Gy)**. It is defined as an energy deposition of one joule per kilogram.

When quoting an absorbed dose, it is important to note the absorbing medium.

The same value of absorbed dose for different types of radiation does not necessarily result in the same degree of biological damage, and this is the concept of **Equivalent Dose**.

For example, 0.05Gy of fast neutrons can do as much biological damage as 1Gy of gamma radiation.

This difference in biological effectiveness needs to be taken into account when doses of different radiations are added to obtain the total biologically effective dose. This is done by multiplying the absorbed dose of each type of radiation by a **Radiation Weighting Factor, w_R** .

The radiation weighting factor is selected for the type and energy of the radiation incident to the body, or in the case of sources within the body, emitted by the source. This weighted dose is the **Equivalent Dose, H_T** .

$$H_T = w_R D_T$$

Where D_T is the mean absorbed dose in a particular tissue or organ. **The SI unit of equivalent dose is the Sievert.**

Dose Equivalent remains, by definition, the absorbed dose multiplied by the quality factor, Q.

The value of the radiation weighting factor depends on the density of ionisation caused by the type of radiation. For example, an alpha particle produces approximately one million ion pairs per millimetre of track in tissue, compared to beta particles, which produce approximately ten thousand ion pairs per millimetre of track in tissue.

w_R is assigned as unity for gamma, X-rays and beta rays, and the values for other types of radiation are related to this.

Radiation Type	Radiation Weighting Factor (w_R)
Gamma & X-rays	1
Beta particles and Electrons	1
Alpha particles and fission fragments	20
Neutrons	5-20 (depending on energy)

Table 1. Radiation Weighting Factors

For non-uniform irradiation to the human body, an annual effective dose equivalent limit of 50 mSv is used. The **effective dose** is defined to take into account the radiological sensitivities of different tissues and organs. The effective dose is the sum of the weighted equivalent doses in all tissues and organs. (Note: The term “effective dose” replaces the quantity “effective dose equivalent” which was previously used).

If the whole body were uniformly irradiated, the fractional contribution of each organ or tissue, T, to the total detriment resulting from exposure to the radiation is represented by a **tissue weighting factor, w_T** .

For example, a dose equivalent to the lung of 50 mSv is the same as an effective dose equivalent of $50 \times 0.12 = 6$ mSv to the whole body. A 50 mSv effective dose would be

the same as $50 / 0.12 = 417$ mSv lung dose.

Tissue/Organ	Tissue Weighting Factor (W_T)
gonads	0.2
Bone Marrow	0.12
Lung	0.12
Colon	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Skin	0.01
Bone Surface	0.01
From ARPANSA Radiation Protection Series No.1, 2001	

Table 2. Tissue Weighting Factors

The following table summarises the relationship between the S.I. units that are now used in Australia and the previously used Empirical Units. Units of radiation are still expressed in Empirical Units in the United States and are still present in many reference books.

Type	S.I. Unit	Symbol	Old Unit	Symbol	Conversion
Activity	Becquerel	Bq	Curie	Ci	$1\text{Ci} = 3.7 \times 10^{10} \text{Bq}$
Exposure	Coulomb/Kg	C Kg^{-1}	Roentgen	R	$1 \text{C Kg}^{-1} = 3876 \text{R}$
Absorbed Dose	Gray	Gy	Rad	rad	$1 \text{Gy} = 100 \text{rad}$
Dose equivalent	Sievert	Sv	Rem	rem	$1 \text{Sv} = 100 \text{rem}$
Effective Dose	Sievert	Sv	Rem	rem	$1 \text{Sv} = 100 \text{rem}$

Table 3. Comparison of Radiation Units

2.1.5.1 Occupational and Public Effective Dose Equivalent Limits

Exposure to radiation is controlled by State or Territory regulatory practices, which are based on the ARPANSA RPS 1 “Recommendations for Limiting Exposure to Ionizing Radiation (Printed 1995 - Republished 2002) and National Standard for Limiting Occupational Exposure to Ionizing Radiation (Printed 1995 - Republished 2002)”. The ARPANSA recommendations are based on ICRP Publication 60, 1991, which contains information and recommendations for occupational and public exposure to radiation.

An **occupationally exposed person** or radiation worker, refers to workers who, as a result of their employment, may be exposed to ionising radiation.

Members of the public refers to all other persons not considered radiation workers.

The ICRP (in Publication 60) recommends an occupational effective dose limit of 20 mSv per year averaged over a five year period, with no more than 50 mSv in any single year. These recommendations have been adopted by the ARPANSA and have subsequently been translated into regulatory requirements for Australian States and Territories.

	Dose Limit	
Applications	Occupational	Public
Effective dose	20 mSv / yr averaged over 5 years (ie, 100mSv averaged over 5 years with a max of 50mSv in any one year)	1 mSv / yr
Annual equivalent dose to:		
eye	150 mSv	15 mSv
Skin (average / cm ²)	500 mSv	50 mSv
Hands/feet	500 mSv	

In a laboratory situation, it is very rare for workers who are practicing good personal hygiene and adopting safe work practices to exceed the 20 mSv per year limit.

Separate effective dose limits are not considered necessary for female radiation workers with reproductive capacity. Where a pregnancy is confirmed, it is recommended that arrangements be made to ensure that the woman works in conditions where it is unlikely that her external skin exposure, during the remainder of her pregnancy will exceed 1 mSv. It is very unlikely that any worker in a laboratory would reach this dose limit under good safe work practices.

Different radioactive materials tend to concentrate in certain tissues more than other tissues. ICRP Publication 68 contains reference to effective dose coefficients for a wide range of radionuclides. From this data, **annual limits on intake (ALIs)** and **derived air concentrations (DACs)** have been calculated so that the primary dose limits will not be exceeded.

AS 2243.4 lists some of the more commonly used radionuclides and their ALI and DAC values. The data are given for guidance only, and are based on the most restrictive assumption, which may lead to an overestimate of the actual dose received. If it is necessary to calculate the best estimate of dose received, (for example, in an accidental exposure situation or when occupational exposure is

close to the limit), data from ICRP Publications 66 and 68 (available at most University libraries) should be used.

2.2 EFFECTS AND RISKS ASSOCIATED WITH RADIATION

2.2.1 General

There is a potential for biological damage, from various radiations, that has been scientifically acknowledged for some time. Non ionizing radiation has its own particular bio-effects associated with the particular type of radiation (electromagnetic fields, static fields, sound). Scientific evidence for causation of biological effect may only exist though for a certain domain of radiation characteristics, (for example across a certain applicable interval of sound frequency and intensity values).

Likewise, ionizing radiation, which has been extensively researched, has its associated risks, and similarly has been demonstrated to cause biological effect in certain systems.

Radiobiology (the study of the biological effects of ionizing radiation) provides much data based upon both experimental work and also observational studies, in addition to various theoretical work. Such scientific work forms the basis of knowledge for the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) and The International Commission on Radiation Protection (ICRP).

2.2.2 Stochastic and Deterministic Effects

In discussing radiation risk, it is convenient to categorise biological effect (as presently done by the ICRP) into two areas:

- i) Stochastic effects
- ii) Deterministic effects (possibly this will be renamed as Non-stochastic).

Stochastic effects are those effects whose probability of occurrence is a function of the radiation dose.

Deterministic effects are those effects whose severity is a function of the radiation dose. Thus, leukemia, solid cancers and genetic effects, are examples of stochastic effects; whilst cataracts, skin erythemas and various 'radiation syndromes' are examples of deterministic effects.

2.2.3 Pregnancy & Foetal Effects

Effects to embryos and developing fetuses can occur. Upon embryonic implantation, or just before, the number of cells is small. Any cell killing will then kill the embryo. Thus radiation induced abortion is essentially a stochastic effect, depending upon whether the cells have been killed or not.

Hence irradiation to the embryo that ultimately develops into a foetus which is then born cannot be considered as having been harmful to the foetus!

However for irradiation within the first months of organogenesis, high rates of cell division leads to high radiosensitivity, and malformations or functional effects can occur. The severity of such effects is an increasing function of dose, and is generally deterministic in nature.

An interesting particular effect is mental retardation. This effect has been demonstrated following Hiroshima and Nagasaki. During organogenesis of the brain, between 8 to 15 weeks post conception, irradiation can result in functional damage realised by mental retardation. It is difficult to determine whether this is a deterministic effect by *data*.

In terms of solid cancer and leukaemia risk to the foetus, the foetus is generally held to be at about the same level of carcinogenic risk as the adult.

ICRP Publication 84 ICRP (Pregnancy and Medical radiation, 84, Elsevier 2001) discusses issues pertaining to irradiation for the pregnant worker and patient (being considered for medical irradiation).

Some of the information abstracted from that report, (officially by the ICRP), is freely available as an electronic document (International Commission on Radiological Protection. ICRP_84_Pregnancy_s.ppt Information abstracted from ICRP *Publication 84*. Available at www.icrp.org Task Group: R. Brent, F. Mettler, L. Wagner, C. Streffer, M. Berry, S. He, T. Kusama) and gives basic information relating to:

- Foetal radiation risks
- Informed consent, notices, pregnancy determination
- Foetal doses from procedures
- Pregnant workers
- Research involving radiation during pregnancy.

For pregnant radiation workers:

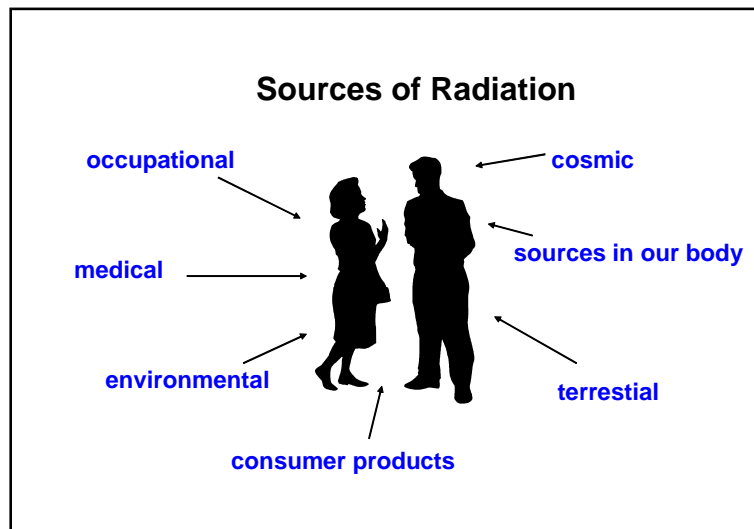
“Pregnant medical radiation workers **may work in a radiation environment** as long as there is reasonable assurance that the Foetal dose can be kept below 1 mGy during the pregnancy.

1 mGy is approximately the dose that all persons receive annually from penetrating natural background radiation.”

2.3 Sources of Radiation

In addition to natural background radiation, there are several sources of non-natural radiation. Radiation comes from fallout as a result of atomic weapons. The medical profession uses x-rays and radiation sources to help diagnose and treat illnesses. Individuals also receive radiation exposures as a result of the operation of experimental and commercial reactors.

Sources of medical radiation exposure include x-rays used for diagnosing or treating patients, radioactive material administered to patients in liquid or gaseous form, and treatments for cancer therapy. The average direct exposure received by an individual in the general population from medical uses of radiation is usually less than 1 mSv per year.



Common examples consumer products are the alpha radiation used in smoke detectors (not normally a hazard unless ingested), building materials, tobacco, and the water supply. Radioactive substances may also be intentionally administered as part of diagnosis or treatment.

2.4 The Tenets of Radiation Protection

Modern radiation protection is based upon the following three principles:

- (i) Justification
- (ii) Limitation
- (iii) Optimisation

- (i) Seeks to ensure that there is no unnecessary irradiation of an individual. Thus, for example, if an X ray examination is not needed to diagnose a medical problem, then it should not be performed.
- (ii) Seeks to limit the dose given below those values that would cause a deterministic effect. That is, this principle intends to guard against a deterministic effect occurring.
- (iii) Seeks to optimise the dose of an individual in such a manner that the dose is 'as low as reasonably achievable' whilst still meeting the objective of the irradiation.

The third principle merits closer consideration. By keeping the dose 'as low as reasonably achievable' (and known as the 'ALARA principle'), this implicitly seeks to reduce the probability of a stochastic effect. The caveat and use of the term 'reasonably achievable' is concerned with the economic and practical circumstances in connection with the instance of the irradiation.

Generally, in many countries, these three (ICRP recommendatory) principles are embodied in law to some degree or another.

Inhalation hazards

The potential hazard posed by inhalation of radioactive material depends on several factors, such as particle size, radiotoxicity, solubility of the contaminant and the physiology of the person.

The size of the inhaled particles determines where within the respiratory system the material will be deposited. Particles of approximately 10 - 100µm are deposited in the nose and throat whilst smaller particles are deposited into the trachea, bronchi and the smaller airways. Depending on where the material lodges, particle size and chemical form, some of the material will pass into the bloodstream and may then concentrate in organs that have a particular affinity for the material, some material may pass into the intestinal tract and some will be exhaled.

Ingestion Hazards

Soluble radioactive material that has been ingested will be distributed in a similar manner to inhaled material. Insoluble material will predominantly pass through the gut and be excreted.

Absorption through the skin

Small amounts of radioactive contamination on the skin can cause a high local dose because of the closeness of the radioactivity to tissues. Any contamination should be removed as soon as possible by washing the area.

Practical control measures that can be implemented at the workplace to control internal hazards include:

- containment of the material - limit the area that could possibly become contaminated by the use of fume cupboards, glove boxes, spill trays and safe work techniques
- good personal hygiene and housekeeping in the work area
- use of the least radiotoxic and smallest activity radioactive material that is suitable for the project being undertaken.

Control of External Radiation Hazards

External hazards refer to the hazards which arise from sources of ionising radiation that are outside the body. External hazards have the potential to irradiate all or part of the body with sufficient energy to affect the skin or underlying tissues.

Practical control measures that can be implemented at the workplace to control external hazards include:

Time

The dose accumulated by a person is directly proportional to the amount of time they spend in the radiation area.

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

The less time spent in a radiation environment the smaller is the radiation dose.

Plan the work to avoid unnecessary exposure. If necessary, a dose rate measurement or estimate can be made and a time limitation set for the work undertaken.

Distance

The greater the distance from a source of radiation the smaller is the radiation dose. For distance, the inverse square law applies, ie. for an isotropic point source of radiation the dose rate at a given distance from the source is inversely proportional to the square of the distance. Thus if you double the distance from a source, the dose rate decreases by a factor of four.

$$D_1 r_1^2 = D_2 r_2^2$$

where D_1 is the dose rate at a distance r_1 from the radiation source, and D_2 is the dose rate at distance r_2 from the same source.

Shielding

Shielding is the practice of placing an attenuating medium between the source of ionizing radiation and the worker. The attenuating medium, or shield, then minimises the radiation that would ordinarily reach the worker. The type and amount of shielding required depends on the type and energy of radiation emitted and its intensity.

If shielding is to work effectively it must be properly designed and made from materials of the appropriate density. Dense (high atomic number) materials (e.g. lead and depleted uranium) make the most effective shields for highly penetrating radiation such as gamma radiation. For lesser penetrating radiation such as beta particles low atomic number materials can be used (e.g. perspex or aluminium).

The most efficient shield is one that has been properly designed for the job, for example:

- the shield may also serve as structural support.

- heavy lead shielding itself may need to be structurally supported, for example, by a heavy steel frame.
- lead glass windows may be required for transparency.
- ideally, shielding should contain no gaps, hence it should be made of one-piece construction or from interlocking blocks.
- the intensity and type of radiation determines what material is required and its thickness.
- shield design must take into account secondary radiation problems (bremsstrahlung) from high energy beta radiation.
- neutrons are effectively shielded by materials containing large quantities of hydrogen, such as polyethylene.

The reduction of exposure by shielding not only requires good design but good management techniques as well. Effective shielding management includes the following items :

- before carrying out an operation involving the use of radioisotopes calculate the shielding requirements using half-value layers or gamma ray constants.
- the quality of the shield should be examined from all directions, including the top and bottom.
- store radioactive materials in appropriately shielded containers with secure lids.
- handle glass vials and test tubes in shielded containers.
- use custom design syringe barrel shields when handling large quantities or activities of an injectable radioisotope.
- to view operations behind a non-transparent shield use a periscope or a leaded glass port - do not directly view the operation.
- the half value layer of a shielding material refers to the thickness of that material, which reduces the intensity of the radiation by 50%.

2.5 REFERENCES AND FURTHER READING

- ARPANSA. *Recommendations for Limiting Exposure to Ionizing Radiation (Guidance Note NOHSC:3022) 1995 and National Standard for Limiting Exposure to Ionizing Radiation (NOHSC:1013) 1995*. Radiation Health Series. Australian Government Publishing Service 1995
- ARPANSA, Radiation Protection Series No.2, Code of Practice “*Safe Transport of Radioactive Material.*” 2001
- ARPANSA. *Code of Practice for Protection Against Ionizing Radiation Emitted from X-ray Analysis Equipment*. Radiation Health Series. Australian Government Publishing Service 1985
- ARPANSA. *Statement on Enclosed X-ray Equipment for Special Applications*. Radiation Health Series. Australian Government Publishing Service 1987
- ARPANSA. *National Guidelines for Management of Clinical and Related Waste*. Australian Government Publishing Service 1989
- ARPANSA. *Code of Practice for the Disposal of Radioactive wastes by the User*. Radiation Health Series. Australian Government Publishing Service 1986
- Attix F H, 1986 *Introduction to Radiological Physics and radiation Dosimetry*, John Wiley & Sons, New York.
- Cember H, *Introduction to Health Physics* 2nd edition. Pergamon Press 1988
- Haski R, Cardilini C, Bartolo W *Laboratory Safety Manual*. CCH Australia 1992
- ICRP Publication 84: *Pregnancy and Medical radiation*, 84, Elsevier 2001
- International Commission on Radiological Protection. ICRP_84_Pregnancy_s.ppt
- Information abstracted from ICRP *Publication 84*. Available at www.icrp.org Task Group: R. Brent, F. Mettler, L. Wagner, C. Streffer, M. Berry, S. He, T. Kusama
- International Commission on Radiological Protection. *Report of the Task Group on Reference Man*. ICRP Publication 23, Oxford: Pergamon Press 1975
- International Commission on Radiological Protection. *Annual Limits on Intake of Radionuclides by Workers Based on the 1990 Recommendations*. ICRP Publication 61, Annals of the ICRP, Oxford: Pergamon Press 1991
- International Commission on Radiological Protection. *1990 Recommendations of the International Commission on Radiological Protection*. ICRP Publication 60, Annals of the ICRP, Oxford: Pergamon Press 1991
- ICRP (International Commission on Radiological Protection). *Recommendations of the*

International Commission on Radiological Protection. ICRP Publication 60. Pergamon Press, Oxford, England. 1991.

Martin A, Harbinson S *An Introduction to Radiation Protection*. 3rd edition. Chapman and Hall 1986

New South Wales Radiation Control Act (1990) and Regulations.

NSW EPA Radiation Control Section *Recommendations for Minimum Standards and Radiation Safety Requirements for Premises on which an Unsealed Radioactive Source is Kept or used*

Shlien B, Slaback Jr L A, Birky B K, 1998 Handbook of Health Physics and Radiological Health, Williams & Wilkins, Baltimore Maryland.

Standards Australia. *Safety in Laboratories AS 2243 Part 4 - Ionizing Radiation* 1998