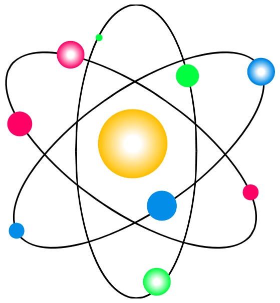
Monash University

Radiation Safety Manual



A joint project by Occupational Health Safety & Environment
&
Ionising Radiation Safety Implementation Advisory Committee

CONTENTS

1. INTRODUCTION

This manual has been produced, to provide practical guidelines for all persons who may come in contact with ionising radiation, to comply with Monash University's (also referred to as "the University") Ionising Radiation Safety Policy Statement (OHS Policy No. 1/92 an hereafter referred to as the "Policy Statement"). The manual has been developed in accordance with the requirements of sections 18 and 19 of the Policy Statement and is intended as a reference source for Radiation Safety Officers and Deputy Radiation Safety Officers.

Appendix A of this manual contains the truncated manual "Manual for Users of Ionising Radiation" which is intended for other radiation workers. The policy requires strict compliance with relevant Victorian and Commonwealth Government legislation, codes of practice, Australian Standards, and recommendations from the International Commission on Radiological Protection (ICRP) and the National Health and Medical Research Council (NH&MRC).

It is stressed that this manual must be read in conjunction with the Policy Statement. A copy of the Policy Statement can be obtained from the department Radiation Safety Officer.

The risk of prosecution by the Department of Health and Community Services or the Health and Safety Organisation of Victoria exists if compliance with all applicable legislation is not fulfilled. In addition, common law actions by individuals against the University for negligence can be based on the allegation of breach of the statutory "duty of care" (in accordance with section 21 of the Occupational Health and Safety Act 1985). Furthermore, failure of the University to give a high priority to compliance with all regulatory requirements in the radiation protection area could invite a negative response including public criticism, adverse media publicity and legislative curtailment of its activities.

2. RESPONSIBILITY FOR IONISING RADIATION SAFETY AT MONASH UNIVERSITY

2.1 The Structure of Responsibility

Ultimate responsibility for ionising radiation safety rests with the University Council. However aspects of this responsibility are delegated throughout the University structure as shown in Figure 1.

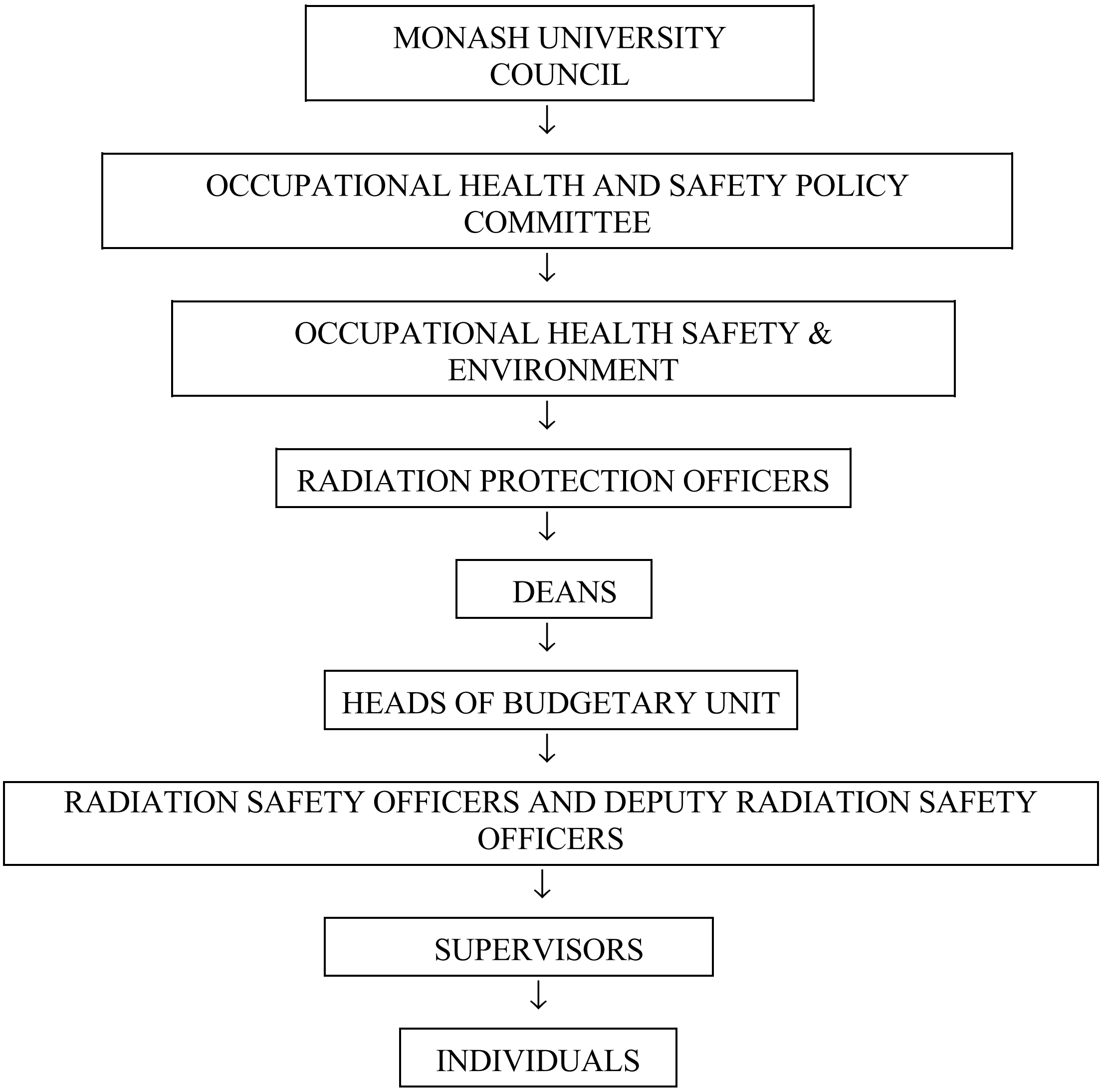


Figure 1: Responsibility for ionising radiation safety at Monash University.

2.2 The Role of Individual Members of the Structure

2.2.1 The University Council

The University Council has ultimate responsibility for ionising radiation safety at Monash University. Their primary function in relation to ionising radiation safety is to choose the direction and extent of change within the University environment. On a more practical level they must approve all policies on ionising radiation safety prior to their enactment.

2.2.2 University Occupational Health and Safety Policy Committee (OHSPC)

The OHSPC has been charged with the primary responsibility of advising the University Council on occupational health and safety matters. It is comprised of employer nominees, employee nominees including representatives of all the major unions, several observers and a secretary who is provided by the Occupational Health and Safety Branch.

The major responsibilities of the OHSPC in relation to occupational health and safety at the University are; ensuring a uniform approach to health and safety issues throughout the University, formulating and reviewing policies and procedures, monitoring compliance with statutory and in-house requirements, monitoring the performance of facilities, departments, centres, units and branches and facilitating cooperation between the University and its employees.

2.2.3 Occupational Health Safety and Environment (OHSE)

The OHSE is the body within the University holding most of the occupational health and safety expertise. In practical terms, OHSE is responsible for the instigation of all occupational health and safety programs, training, policies and procedures, advice and other matters. The Radiation Protection Officers are members of OHSE. The OHSE should be contacted to deal with occupational health and safety issues that a supervisor, health and safety representative or departmental specialist officer (radiation, laser, biosafety or safety) cannot deal with.

Position	Person	Phone Number
Manager	Mr Paul Barton	54049
Radiation Protection Officer	Ms Margaret Rendell	51060
Assistant Radiation Protection Officer	Mr Sam Zouzounis	54059
Environmental Adviser	Ms Michelle Giovas	51018
OHSE Consultants		
(Medicine)	Dr Simon Barrett	55739
(Science)	Ms Sharon Lockhart	51627
(Engineering)	Mr John Whale	51021
Occupational Health Nurse Consultants	Mrs Anne Tapley Ms Angela Wall	51014
Occupational Health Physician	Dr. Vicki Ashton	51166
General Enquiries		51016

Table 1: Members of the OHSE at Monash University

The numbers listed above are the extension numbers. If you cannot ring these types of extension numbers then you will need to add 990 in front of the numbers listed to contact OHSE.

2.2.4 Radiation Protection Officer (RPO)

In accordance with the requirements of the Policy Statement and the Health Act of 1958, the University must have the equivalent of a full time RPO. A full position description for the RPO including responsibilities, duties and authority conferred is included in the Policy Statement. In summary the RPO/s are the University's in-house experts on radiation safety and representatives who communicate with the Health Department of Victoria on all radiation safety matters. The RPO should be consulted when the Departmental Radiation Safety Officer or deputy is unable to answer any query on radiation safety.

The names and contact numbers of the RPOs are included in section 2.2.3.

2.2.5 Deans

The dean of a faculty does not directly contribute to radiation safety matters within departments, as this is the responsibility of department heads. However, the dean will at times receive communications on general radiation safety matters in the form of general directives from the Manager of OHSE or a higher authority.

2.2.6 Heads of budgetary units

Heads of budgetary units have the most responsibility for radiation safety of individual radiation workers, non-radiation workers and members of the public who are under their jurisdiction. They are responsible for appointing radiation safety officers and deputies, putting into place all directives from higher authorities in relation to radiation safety and delegating duties or authority in relation to radiation safety. A full description of the duties of heads of budgetary units is included in the Policy Statement.

2.2.7 Departmental Radiation Safety Officer (RSO) and Deputy Radiation Safety Officer (Deputy RSO)

The RSOs and deputy RSOs are the radiation safety experts at the departmental level. These positions are best suited to either academic or general staff with considerable experience in working with ionising radiation, although senior students may be permitted to take this role under some circumstances. At the current time, the RSOs and deputy RSOs are also responsible for non-ionising radiation safety.

The RSOs and deputy RSOs are responsible for enacting university policies, procedures and other directives at the departmental level, assisting individuals with queries on radiation safety matters and liaising with the RPOs. A full position description for the position of RSO or deputy RSO, including responsibilities, duties and authority conferred is included in the Policy Statement.

2.2.8 Supervisors

As with all occupational health and safety issues, supervisors have immediate responsibility for the safety of their subordinates who are using ionising radiation. They may be delegated responsibilities by the RSO or deputy RSO. These responsibilities may include information dissemination, checking procedures, and contamination monitoring. When a query in relation to ionising radiation safety is raised, the supervisor should always be the first point of contact in resolving the issue. A detailed description of the responsibilities of supervisors in relation to ionising radiation safety is set out in the Policy Statement.

2.2.9 Individuals

A department holding or using ionising radiation may consist of three types of individuals. These are; radiation workers (the people who use the ionising radiation), non-radiation workers (people who do not use ionising radiation as part of their work but who may come into contact with it in carrying out their normal duties) and members of the public (visitors to the department who do not work there but may have cause to come across ionising radiation).

All individuals within a department that uses or stores ionising radiation are required by the Policy Statement to behave in a responsible manner and to obey instructions given in relation to their safety in the presence of ionising radiation. Full details of the responsibilities of individuals are contained in the Policy Statement. Individuals working with ionising radiation within the department should receive some training in ionising radiation safety as part of the requirements of the Policy Statement.

2.3 The Support Structure

2.3.1 General

The structure of responsibility is complemented and supported by health and safety representatives, safety officers and zone occupational health and safety committees. The people who fill these positions liaise with all levels of the support structure.

2.3.2 Health and Safety Representatives

Health and safety representatives are appointed by the employees of a particular workplace or part thereof. There are several dozen health and safety representatives at Monash University, each representing a different "designated work group". They liaise mainly with the zone occupational health and safety committees, individuals and the OHS Branch. They have special powers under the Occupational Health and Safety Act 1985 which may be applied to ionising radiation safety and are detailed in the University's Occupational Health and Safety Policy Statement (OHS Policy Number 1/88).

In relation to ionising radiation safety their role is rarely that of a technical expert. However, as they are very familiar with correct procedures for dealing with health and safety issues they are an excellent point of call when an RSO or Deputy RSO is unavailable.

2.3.3 Safety Officers

Safety officers are appointed by heads of budgetary units, and may obtain many of their directives from their Zone Occupational Health and Safety Committee. They are usually general or academic staff with a good general knowledge of safety issues and a thorough knowledge of the department in which they work. They generally liaise extensively with OHSE, individuals and their Zone Occupational Health and Safety Committee. The role of a departmental safety officer is detailed in the University's Occupational Health and Safety Policy Statement.

In relation to ionising radiation safety, the role of a safety officer is rarely that of a technical expert. However, as they are very familiar with correct procedures for dealing with health and safety issues and are general safety experts, they are an excellent point of call when an RSO or Deputy RSO is unavailable.

2.3.4 Zone Occupational Health and Safety Committees

The terms of reference for zone occupational health and safety committees are described in the Occupational Health and Safety Policy Statement. In relation to ionising radiation safety these committees serve to bring together the expertise of RSOs, deputy RSOs, safety officers, health and safety representatives and senior staff members within the department. In particular, they have an important role to play in the discussion and followup of incidents involving ionising radiation, or for provision of advice on the implementation or development of ionising radiation safety policies and procedures.

3. THE FORMATION OF IONISING RADIATION

3.1 Atomic Theory

All matter as we know it is made up of **ATOMS**. For example, your desk, chair, telephone, clothes and the food you eat are all made up of atoms. The smallest single entity of each of these objects is an atom.

There are 106 different types of atoms known to man and these are called **ELEMENTS,** each has its own symbol. Examples of different elements are shown in Figure 2.

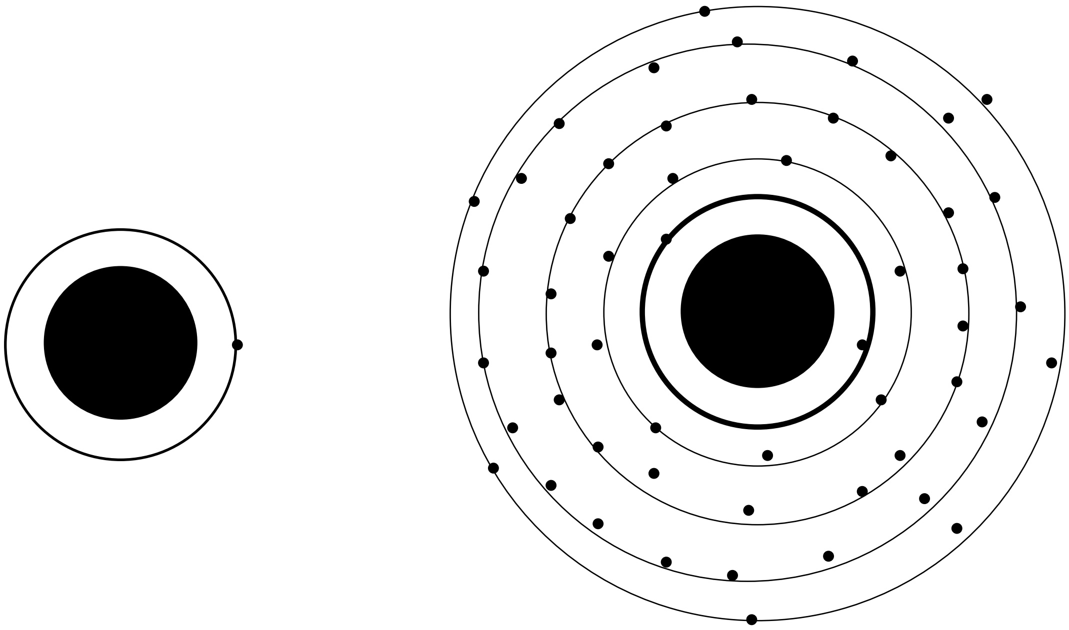
Element	*Symbol*
Hydrogen	*H*
Carbon	*C*
Zinc	*Zn*
Iodine	*I*

Figure 2: Examples of some elements from the periodic table

All atoms of an element are tiny, measuring only fractions of a metre in diameter. Hydrogen is the smallest atom and measures approximately 0.3 x 10^{-10} metres in diameter. Scientists believe that atoms look like a miniature solar system where the nucleus of each single atom within an element, is orbited by a number of single charge, negative particles called **ELECTRONS (e^-).**

Electrons exist in **SHELLS**, which are at varying distances from the nucleus. The **SHELLS** most distant from the nucleus contain electrons with the highest energy.

To balance the negative charge of the electrons, the nucleus of the atom contains positively charged particles called **PROTONS (H^+)** and these are held in close proximity by **NEUTRONS (n).** A proton and a neutron are both defined as having an **ATOMIC MASS UNIT (amu)** of 1. The specific identity of an element is dependent on the number of protons held within each atom. The hydrogen atom is the simplest of all the elements and contains 1 proton and 1 electron. It is shown in Figure 3 beside the iodine atom which contains 53 protons, 74 neutrons and 53 electrons:



Hydrogen *Iodine*

Figure 3: The atomic configuration of the hydrogen and iodine atoms.

When a number of atoms of the same or different elements are bonded together, they form a **MOLECULE** or **COMPOUND.** There are millions of molecules known and they range in size from little more than an atom, to large enough to be viewed through a powerful microscope. DNA is a molecule, other examples of molecules are shown in Figure 4.

Water (2 hydrogen and 1 oxygen atom) *Chlorine gas (2 chlorine atoms)*

Figure 4: Examples of small molecules

3.2 The Process of Radioactivity

A neutral atom consists of neutrons, protons and electrons. The nucleus of the stable atom is held together by attractive forces between the protons and neutrons, which must be strong enough to overcome the repulsive forces between the protons. Because of this repulsive force, the ratio of neutrons to protons increases for stable isotopes as the atomic number increases.

For a variety of reasons, a particular element may contain atoms having different numbers of neutrons but the same numbers of protons. These different types of atoms of a single element are called **ISOTOPES** and they are listed for the element hydrogen in Figure 5.

Isotope	*Composition*
Hydrogen gas	*1 proton, 1 electron and 1 neutron*
Deuterium	*1 proton, 1 electron and 2 neutrons*
Tritium	*1 proton, 1 electron and 3 neutrons*

Figure 5: The isotopes of hydrogen

Emission of radiation or **RADIOACTIVITY** comes about because the atoms of a particular isotope are unstable due to the masses and charges being held within the nucleus. Isotopes emitting radioactivity are called **RADIOISOTOPES** or **RADIONUCLIDES**.

The exact reasons for radioactivity are not well understood. However, it is believed that an excess or deficiency in the number of neutrons confers instability within a nucleus. Radioactivity leads to the emission of alpha (α), beta (β), gamma (γ) or X-rays or neutrons in a continuing process (chain) until a final stable decay product is reached.

Given that the most desirable state for any atom is stability, the atoms of isotopes with excess numbers of neutrons will undergo radioactive decay and emit radiation until they attain stability. The types of radiation may include alpha, beta, gamma and X-rays. These represent the emission of differing amounts of energy and mass from the atoms. The most well known radioactive decay chain is that of uranium-238. Each step in figure 6 shows the type of radiation that is lost.

$$\begin{tikzcd}
{}^{238}_{92}\mathrm{U} \arrow[r, "\alpha"] & {}^{234}_{90}\mathrm{Th} \arrow[r, "\beta"] & {}^{234}_{91}\mathrm{Pa} \arrow[r, "\beta"] & {}^{234}_{92}\mathrm{U} \arrow[r, "\alpha"] & {}^{230}_{90}\mathrm{Th} \arrow[r, "\alpha"] & {}^{226}_{88}\mathrm{Ra} \arrow[d, "\alpha"] \\
& {}^{214}_{84}\mathrm{Po} \arrow[d, "\alpha"'] & {}^{214}_{83}\mathrm{Bi} \arrow[l, "\beta"'] & {}^{214}_{82}\mathrm{Pb} \arrow[l, "\beta"'] & {}^{218}_{84}\mathrm{Po} \arrow[l, "\alpha"'] & {}^{222}_{86}\mathrm{Rn} \arrow[l, "\alpha"'] \\
& {}^{210}_{82}\mathrm{Pb} \arrow[r, "\beta"] & {}^{210}_{83}\mathrm{Bi} \arrow[r, "\beta"] \arrow[d, "\alpha"'] & {}^{210}_{84}\mathrm{Po} \arrow[r, "\alpha"] & {}^{206}_{82}\mathrm{Pb}\text{ (stable)} & \\
& & {}^{206}_{81}\mathrm{Tl} \arrow[urr, "\beta"'] & & &
\end{tikzcd}$$

Figure 6: The decay chain of uranium-238

It should be noted that whether the process of radioactive decay is artificially induced or naturally occurring, the rules for the decay are the same in both instances.

3.3 Activity

The quantity used to describe the amount of radioactive material present is **ACTIVITY**. This is the number of disintegrations per unit time. The SI unit for activity is the Becquerel (Bq) in disintegrations per second. The imperial unit is the Curie (Ci).

$$1 \text{ Bq} = 1 \text{ dps}$$
$$1 \text{ Ci} = 3.7 \ ' \ 10^{-10} \text{ Bq}$$

The process of radioactive decay is an exponential process and is described by the formula:

$$A_t = A_o \, e^{-\lambda t}$$

Where: A_o is the original activity
A_t is the activity at time t
λ is the radioactive decay constant

Graphically, the process of radioactive decay may be represented as an exponential decay of the form shown in Figure 7.

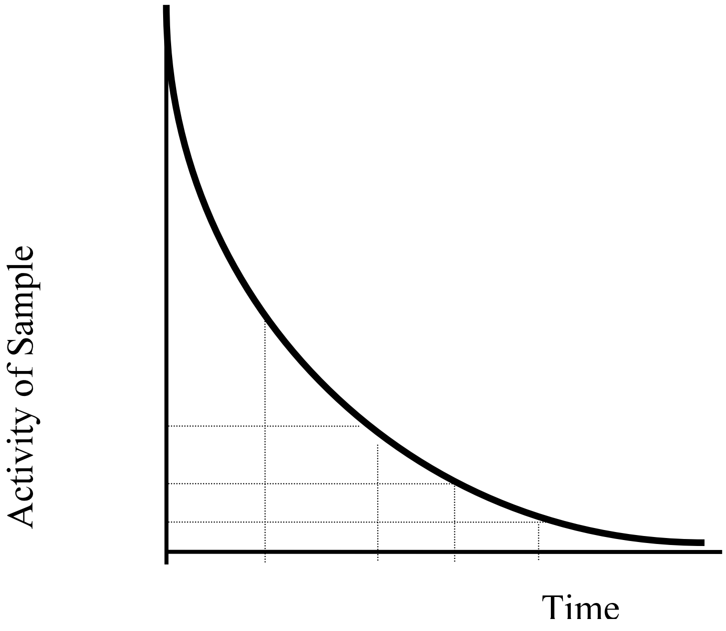


Figure 7: The pattern of radioactive decay

3.4 The Concept of Half-Life

The **HALF-LIFE** ($t_{1/2}$) of a radioisotope is defined as the time for a known quantity of an isotope to decay to half of its original activity (A_o). Half-life is determined from the equation:

$$t\tfrac{1}{2} = \underline{0.693}$$

$$\lambda$$

or if λ is unknown: $A_t = A_o\, e^{-0.693/t_{½}}$

An easier working equation that is often used is:

$$A_t = \frac{A_o}{2^n}$$

Where n is the number of half-lives expected in time t

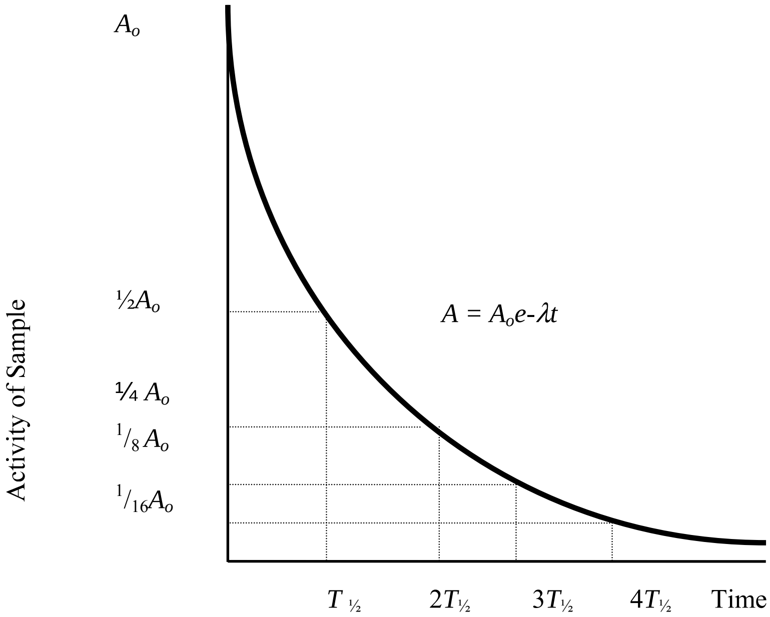


Figure 8: the half life of an isotope

The half-life is a unique quantity for a particular radioisotope. Half-lives for a particular element can vary enormously. For example, thorium-235 has a half-life of 7.2 minutes whereas thorium-232 has a half-life of 1.4×10^{10} years.

3.5 Types of Ionising Radiation

3.5.1 Particulate Radiation

3.5.1.1 Alpha radiation (α decay)

Type: Particulate consisting of a slow moving, highly stable helium has two protons, two neutrons and two units of positive charge. Each alpha particle ($^{4}_{2}He$) has a mass equivalent to four amu.

Formation: Alpha radiation is emitted by some of the heavier elements in their efforts to reduce the total numbers of protons and neutrons (mass) within their nuclei. The effect is to stabilise neutron rich nuclei. However sometimes the nucleus may still be unstable after decay and as a result beta decay may occur.

e.g. $^{240}_{95}Am \rightarrow {}^{236}_{93}Np + {}^{4}_{2}He\ (\alpha)$

Range: Typically alpha particles travel only a few centimetres in air and only a few millimetres within tissue or paper. For example a 3.5 MeV alpha particle will travel approximately 20 millimetres in air and 0.003 millimetres in tissue.

Speed: Speed at a specific time will depend on the energy of the specific α particle, and how far it has traversed through matter. Initial speed depends on the energy of the radiation and typical speeds are in the range of 10^9 cm/sec. Alpha particles slow and eventually stop in their passage through matter as they give up their energy.

Ionising potential: The greatest ioniser of all radiation types due their high linear energy transfer (LET) potential. A single 3.5 MeV alpha particle will produce approximately 10^5 ion pairs in air before coming to rest.

Energies: In general less than 7 MeV.

Examples: Natural radioisotopes such as uranium-234, thorium-230 and radium-226. Polonium-210 is a man-made alpha emitter and is the main component of fuel for nuclear power plants.

3.5.1.2 Beta radiation (β decay)

Type: Particles consisting of fast moving electrons with a single negative charge that have a mass of 1/1840 of an amu and originate from atomic nuclei. They are produced by neutron abundant nuclei in their attempt to gain neutron-proton balance.

Formation: Beta decay may occur in any nuclear species that has an excess of neutrons, irrespective of its mass. Beta particles are always emitted alone and result in an increase in the number of protons as a neutron is transformed into a proton and an electron.

e.g. $^{32}_{15}\mathrm{P} \rightarrow {}^{30}_{14}\mathrm{Si} + e^{-}(\beta)$

Speed: Initial speeds are in the vicinity of 10^{10} cm/sec, this is slightly faster than alpha particles. The speed of the beta particle is attenuated by the medium through which it travels until the particle comes to a complete halt.

Range: In general a few metres in air and a few centimetres in tissue. They have a range higher than most alpha particles and lower than most gamma rays. For example, a 3.5 MeV beta particle will travel approximately 11 metres in air and 15 millimetres in tissue.

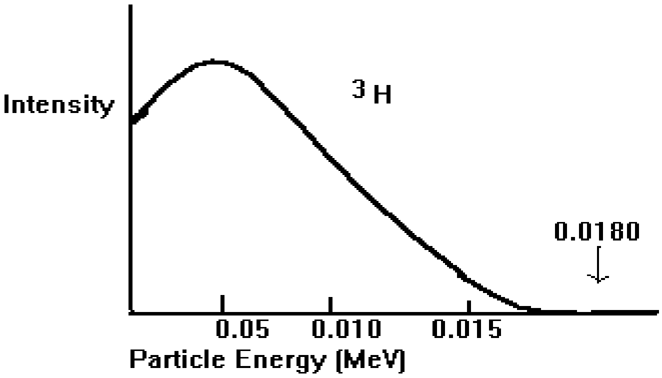
The formulae for the ranges of beta particles are complex. A good "rule of the thumb" for the higher energy beta particles, is:

$$R \cong 0.5\,E_{max}$$

Where: R = range (gcm^{-2})
E = energy (MeV)

Ionising potential: A significant ioniser with reduced LET when compared to an alpha particle. Beta particles produce ionisation by interacting with electrons in atomic or molecular orbits.

Energies: The energy of the beta particle may be any value up to that of the total energy (E_{max}) of the transformation (continuous energy distribution). The range of energies typically seen is from 1000 eV to 5 MeV. The difference between E_{max} and the beta particle energy is carried off by another particle called a **NEUTRINO**. Neutrinos have no relevance to radiation protection. Only a small fraction of the beta particles given off from the decay of a particular nuclide will have energies of E_{max}. The most probable beta energy = 1/3 E_{max}.



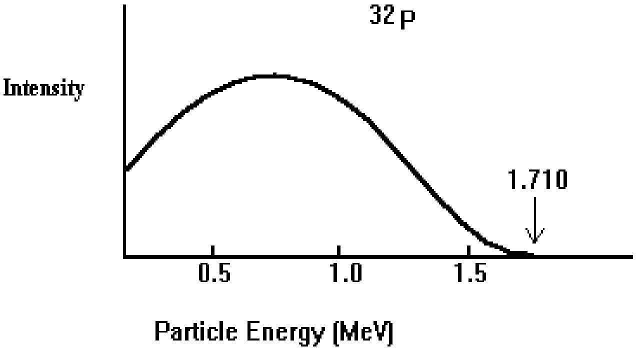


Figure 9: Energy spectra for β-radiation

Examples: Some examples of beta emitting nuclides are; carbon-14, tritium, (hydrogen-3) sulphur-35, calcium-45, phosphorous-32, and strontium-90.

3.5.1.3 Neutron radiation

Type: Neutral, particulate radiation with a mass of one amu.

Formation: There are no significant naturally occurring neutron emitters because radioisotopes with excess neutrons will preferentially undergo beta emission rather than select to emit a neutron. Neutron emitting radionuclides can be produced artificially by bombardment of the stable nuclei and subsequent fission. This process is usually undertaken in a nuclear reactor.

Range: In human tissue, the average distance of penetration varies from 0.6 centimetres to nearly 10 centimetres depending on the energy of the neutrons.

Speed: All neutrons start life as fast neutrons. They are slowed down by either elastic or inelastic collisions with nuclei of absorber atoms. The average speed of a neutron varies between 10^3 - 10^6 m/s.

Ionising potential: Neutrons are uncharged. Therefore, the mechanism of ionisation is indirect and involves the transfer of energy to other atoms, which then de-excite by emitting other particulate or electromagnetic radiations. Neutrons will only interact appreciably with small atomic nuclei of roughly similar mass to the neutron. This makes paraffin a much better absorber than lead. They have a very long range in matter ($\cong$ 1m in water). The extent of ionisation that occurs depends on the energy of the neutron. Neutrons are considered to be high LET radiation.

Energies: Neutrons are divided into 2 groups based on their energy:

Fast neutrons: > *0.1 Mev*

Thermal or slow neutrons: < 0.1 Mev

Examples: Californium-252 is the only useful example (sufficient length of half-life) of an artificially produced radionuclide that spontaneously undergoes fission and subsequent emission of neutrons.

3.5.2 Electromagnetic Radiation

3.5.2.1 Gamma radiation

Type: Electromagnetic radiations consisting of packets or **PHOTONS** of energy.

Formation: Most nuclear transformations result in an excited nucleus remaining after the particle radiation has been ejected. To correct this, the nucleus will emit energy to reach a more stable state. This energy is called Gamma radiation. Thus, Gamma formation usually accompanies emission of either alpha or beta radiation or electron or neutron capture.

Range: Gamma radiation has the largest range of all radiation types. Gamma photons will travel indefinite distances unless intercepted by a medium having atoms that will interact to take up the energy and extinguish the radiation. Gamma radiation will pass right through the human body and travel for many metres in air unless blocked by a suitable shield.

Speed: Gamma rays do not slow as they travel through matter. Their speed (c) is always that of light. i.e. 3×10^8 ms^{-1} or 18,600 miles s^{-1}.

They will come to a stop only when they lose sufficient energy through interactions with atoms. The speed of electromagnetic radiation is related to its frequency and wavelength as follows:

$$c = f\lambda$$

Where: f = frequency (cycles/second)
λ = wavelength (metres)

Ionising potential: Gamma radiation causes little ionisation within any medium that it passes through when compared with the particulate radiations. It has low LET. Ionisation due to gamma is due to secondary ionisation by the mechanisms of photoelectric effect, Compton effect or pair production. (see section 4)

Energies: Energies vary from approximately 1000 eV to 10 MeV. Energy obeys Planck's law:

$$E = hf\,(eV)$$

Where: h = Planck's constant (6.634×10^{-34} Js)

Examples: Calcium-47, iodine-125, cobalt-60 and caesium-137.

3.5.2.2 X radiation

Type: Electromagnetic radiation consisting of photons of energy.

Formation: There are two mechanisms by which X rays are produced:

- The first is by acceleration or deceleration of charged particles as they pass through the electric field of an atom in an absorbing material. In an X- ray tube this occurs by the impingement (and resulting deceleration) of high-speed electrons onto a metal surface after acceleration through a voltage gradient.

  The X radiation formed by the deceleration of beta radiation within an absorbing medium such as lead is known as **BREMSSTRAHLUNG.** The amount of bremsstrahlung produced increases with the density of the absorbing medium due to the increased rate of deceleration. The fraction (F) of beta energy converted to X radiation by this means is given by:

  $$F = 3.3 \times 10^{-4}\, ZE_{max}$$

  Where: Z = the atomic number of the absorbing medium
  E_{max} = the maximum energy of the beta radiation

  Like beta radiation, Bremsstrahlung also has a continuous energy spectrum because varying amounts of the energy of the decelerating electrons are converted to X-rays.

- The second mechanism involves the movement of outer shell electrons to gaps made in inner shells of an atom by earlier excitation of that atom. The atom rearranges its electrons in this manner in order to return to the ground energy state. Unlike X rays that have been produced by acceleration or deceleration of charged particles, these X rays do not have a continuous energy spectrum. Their energies are discrete and represent the difference in energy between the shells involved.

This mechanism of X ray production is of importance in commercial X ray machines. The removal of the inner shell electron from an atom in the initial stages of X ray production may be brought about in several different ways:

- ∗Bombardment with energetic electrons such as in an X ray tube.
- ∗Gamma rays interacting with an atom in the photoelectric effect.
- ∗Two other forms of radioactive decay; internal conversion and electron capture (beyond the scope of this manual).

Range: X radiation has travel ranges that vary enormously according to energy. In theory X radiation will travel indefinite distances (i.e. in a vacuum) unless intercepted by a medium having atoms that will interact to take up the energy and extinguish the radiation. Powerful X radiation will pass right through the human body and travel for metres in air unless blocked by a suitable shield. In general, X radiation does not travel as far as gamma radiation. HARD X rays are those that travel long distances and SOFT X rays are those that travel only a short distance.

Speed: X rays do not slow as they travel through matter. Their speed is always that of light as they are an electromagnetic radiation form, i.e. 3×10^8 m/sec. They will come to a stop only when they lose energy through interactions with atoms.

Ionising potential: X radiation causes little ionisation within any medium that it passes through when compared with the particulate radiations. It has low LET. Ionisation due to X is exclusively due to secondary (indirect) ionisation by one of the processes of photoelectric effect, Compton effect or pair production (see section 4).

Energies: Energies vary from approximately 1000 eV to 10 MeV. Energy obeys Planck's law. $E = hf$ and may be in a continuous frequency spectrum or exist at discrete frequencies.

Examples: X ray machines and X ray diffractometers.

4. THEORY OF INTERACTION OF RADIATION AND MATTER

4.1 Charged Particle Interactions

Application: Alpha and beta radiations, which all ionise directly.

Mechanism: The mode of interaction between a charged particle and the atoms of any involved medium is one of inelastic collision. Outer shell electrons are always the part of the atom that participates in such a collision and they may be in inner or outer shell positions. Such a collision of the electric fields of two charged particles (but not the particles themselves) results in one of two outcomes:

- **Ionisation:** The electron is expelled from the atom resulting in ionisation. This is common where alpha is the charged particle that participates. The large mass and charge of an alpha particle will ensure complete ionisation of the atom. The free ion then pairs up with an ion of opposite charge in order to gain neutrality.

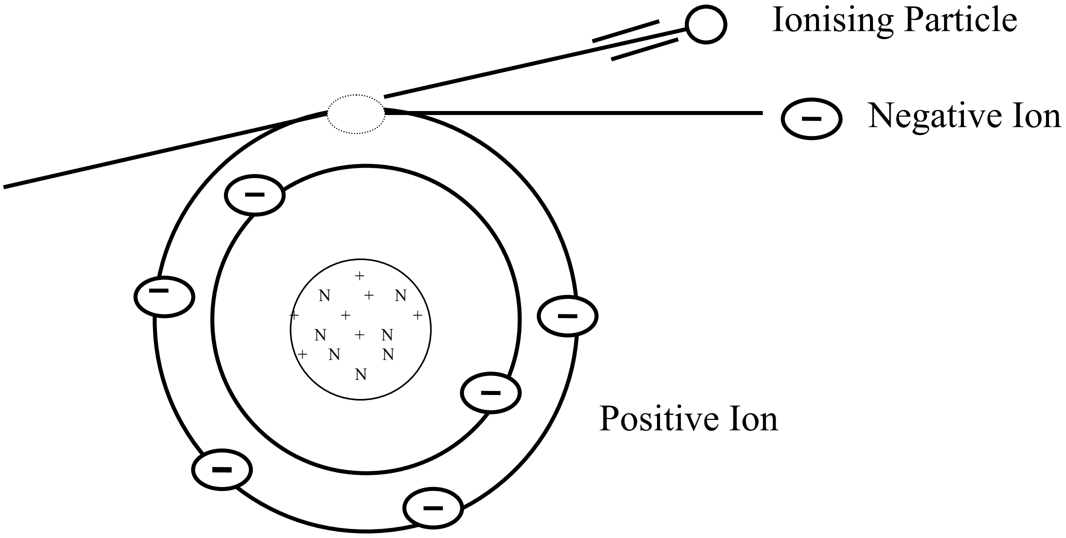


Figure 10: β-Emission

- **Excitation:** The electron may simply gain sufficient energy from the collision to proceed to a higher energy shell, which is further out from the nucleus. This puts the atom in an excited state. The electrons in the atom may then rearrange in order to return the atom to the ground energy state. This often results in the emission of X radiation of discrete frequencies.

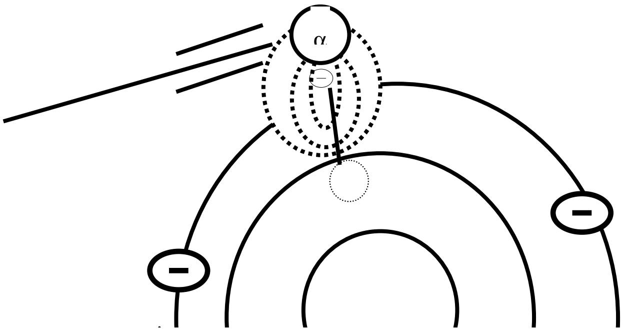


Figure 11 X-Ray Emission

4.2 Photon Interactions

Application: X and gamma radiations.

Mechanism: There are three different types of interactions that occur as a consequence of direct contact between electromagnetic radiation and the atoms of an involved medium:

- **The photoelectric effect:** A low energy gamma photon (less than 1 MeV) interacts with a tightly bound, inner shell electron of a heavy atom, e.g. Lead. The ejected electron assumes the entire energy of the now non-existent photon and travels out to effect secondary ionisation. The vacancy is usually filled by rearrangement of an outer electron to the space in the inner shell and emission of one or more frequency characteristic X rays.

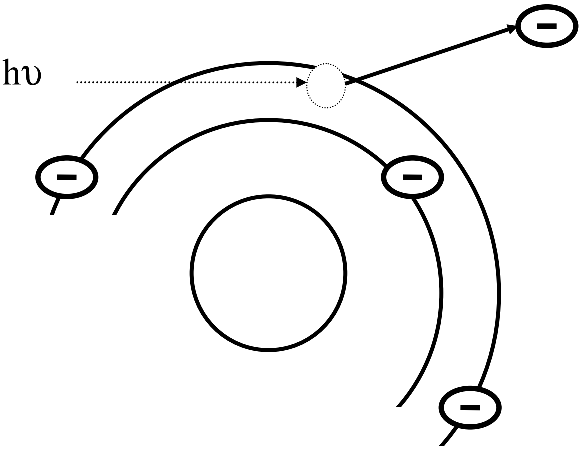


Figure 12: Photoelectric effect

- **Compton scattering:** Gamma rays of energy 0.2 to 5 MeV may undergo an elastic collision with a loosely bound outer electron of an atom having an intermediate mass e.g. Iron. Only some of the photon's energy is taken up in ejecting the electron from the atom and the photon is also scattered with reduced energy and a longer wavelength. The ejected electron may go on to produce secondary ionisations.

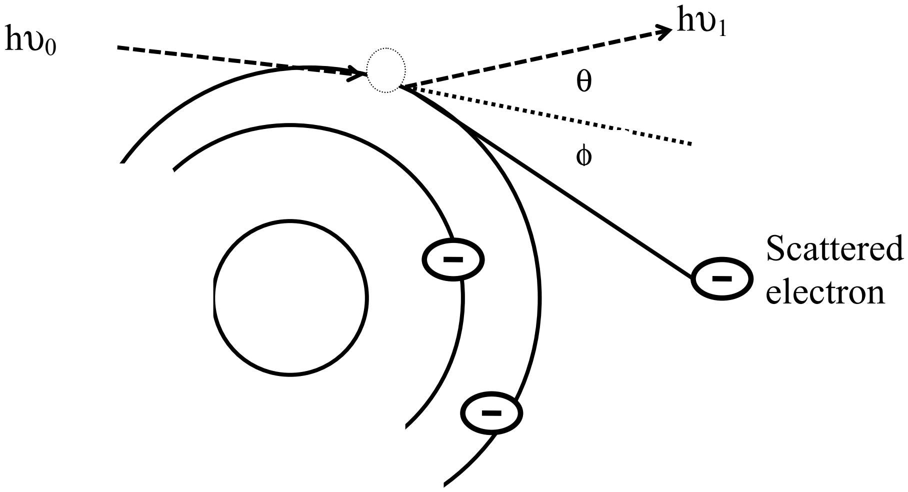


Figure 13 Compton Scattering

- **Pair production:** A gamma photon having an energy greater than 1.02 MeV may interact with the electric field surrounding a heavy nucleus (e.g. lead) and give up its energy to form and electron and a positron (positively charged electron; the formation of which is beyond the scope of this manual). These two particles lose energy in the process of secondary ionisation. The positron may then interact with another electron in a process called ANNIHILATION. The two particles convert to two gamma rays of 0.51 MeV each and travel in opposite directions to one another.

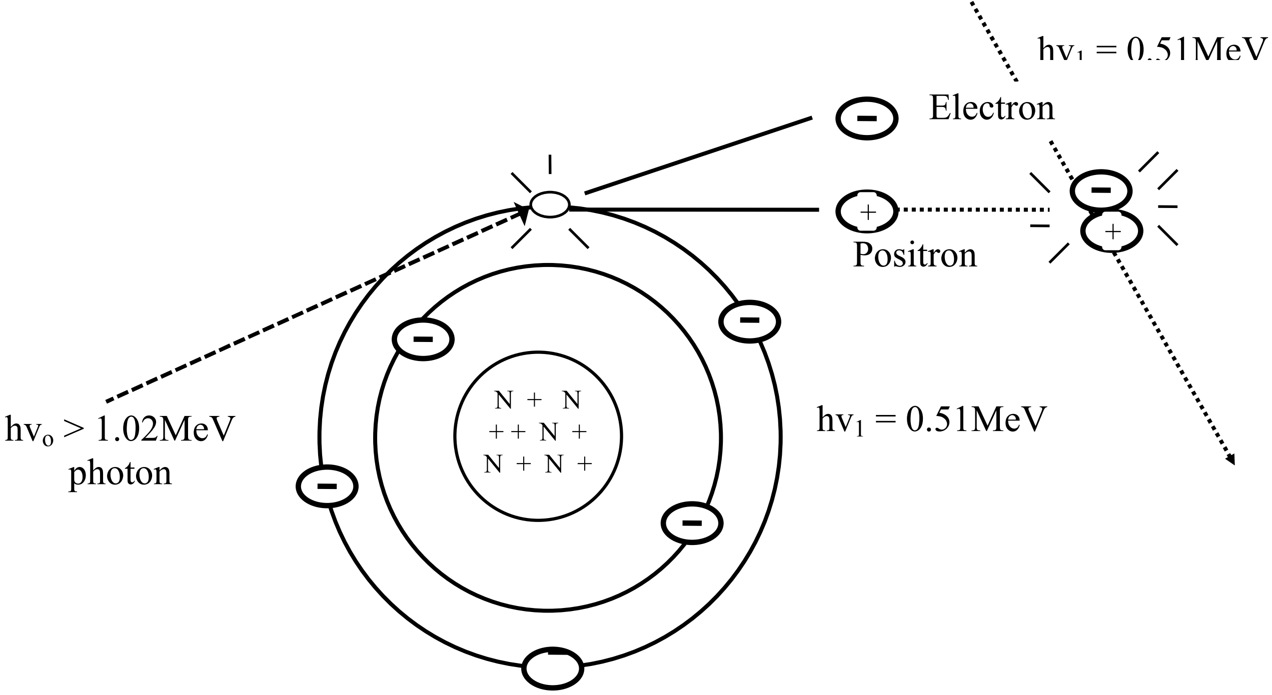


Figure 14 Pair Production

4.3 Neutron Interactions

Application: Fast and thermal neutrons.

Mechanism: The interactions that occur between neutrons and the atoms of involved materials are of the billiard ball type and involve direct contact between the neutron and the atom (nucleus in particular). There are three different types of collisions:

- **Elastic scattering:** This is the predominant mode of interaction for fast neutrons that interact with light nuclei. The neutron continues on after the collision with a reduced energy and changed direction. The energy lost by the neutron has been totally transferred to the atom in the form of kinetic energy and the atom moves according to its new energy.

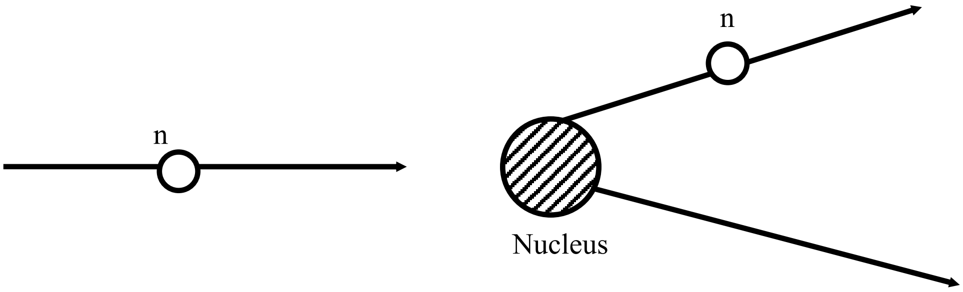


Figure 15: Elastic Scattering

- **Inelastic scattering:** When neutrons collide with the nuclei of heavy atoms a proportion of the neutron's energy is imparted to the atom's nucleus which becomes excited. The neutron will be deflected off in another direction with reduced energy. The nucleus de-excites almost immediately by emitting a gamma photon (Diag. 7).

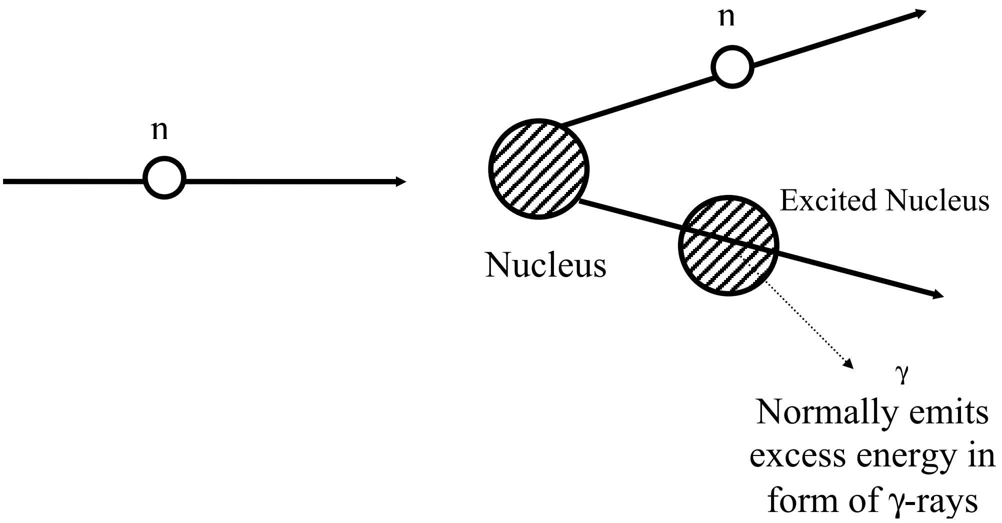
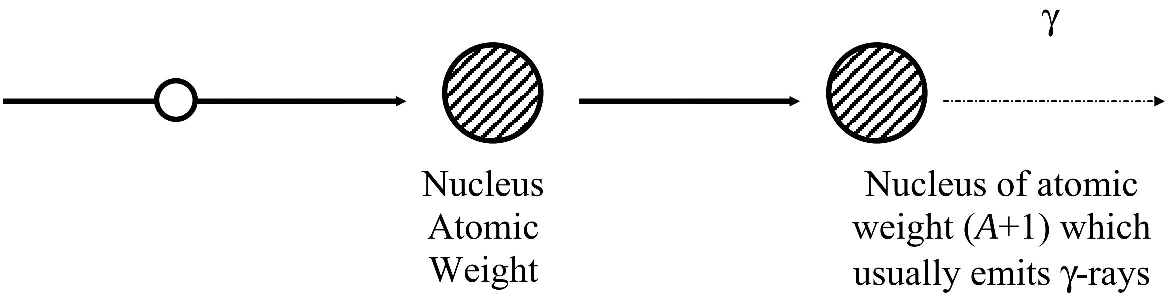


Figure 16: Inelastic Scattering

- **Capture:** This is the predominant mode of interaction for thermal neutrons. When they collide with the nucleus of the involved atom, they become part of it thus elevating the nucleus to an excited state. The nucleus of the atom usually responds by emitting gamma rays in order to return to the ground state. In some cases alpha or proton emission or fission may occur. This process may render an inappropriately chosen shielding material radioactive <u>after</u> exposure to neutrons.



<u>Figure 17: Neutron Capture</u>

5. THE INTERACTION OF IONISING RADIATION WITH BIOLOGICAL MATTER

5.1 The Mechanism of Effect

Ionising radiation adversely affects human tissue by causing ionisation within the molecules of that tissue. Commonly the first molecule to be involved is water and ions are produced that carry single positive or negative charges. The first reaction that occurs is usually:

$$H_2O \text{ (water)} \rightarrow H_2O^+ \text{ (hydronium ion) and 1 electron}$$

This is followed by interaction between the hydronium ion and the electron and other water molecules resulting in a variety of new products including; H^+ (hydrogen ion), OH^- (hydroxyl ion), $H^{\cdot}$ and $OH^{\cdot}$ (hydrogen and hydroxy radicals). The hydrogen and hydroxyl ions take no further part in further reactions, but the hydrogen and hydroxy radicals may interact with themselves or other molecules. For example, two hydroxy radicals may react to form hydrogen peroxide.

$$OH^{\cdot} + OH^{\cdot} = H_2O_2 \text{ (hydrogen peroxide)}$$

The radicals and hydrogen peroxide can then react chemically with, and consequently alter, important molecules within human cells. This process of ionisation and the concomitant heating of the cell contents may either destroy the cell outright at the time or result in changes to the genetic material within the cell. These changes come about as a result of the ions reacting with DNA in the cell nucleus.

5.2 The Interaction of Ionising Radiation with Human Tissue

5.2.1 Introduction

A living human cell can be thought of as having metabolic, functional and usually reproductive activity. Only cells from the central nervous system (neurones and parts of the spinal chord) and the female germ cells do not reproduce, and are therefore not replaced. Other cells such as those of the liver reproduce very slowly. For the purposes of ionising radiation safety, death of a cell is regarded as the inability of that cell to reproduce due to the effects of the ionising radiation.

Where the cell is not killed by the initial exposure to ionising radiation, other conditions may result such as; blocked or delayed cell division or transmission of a mutated gene to the progeny. In many cases, a damaged cell may be prevented in its first or later attempts to reproduce.

Low LET radiation (X, gamma and beta) tends to inflict more sublethal damage that can be repaired at a later stage than high LET radiation (alpha and neutrons). It transfers relatively little of its energy to the tissue per unit path length, ionising indirectly and may travel right through the body. High LET radiations deposit a lot of their energy per unit path length and tend to ionise directly causing greater damage but travelling only a relatively short path through the tissue. The difference in the two mechanisms of tissue damage lies in the speed of particulate radiations and the energy of electromagnetic radiations.

For low LET radiation, the proportion of sublethal injury to cells contributes very significantly to the overall injury. This proportion reduces with increasing LET. Consequently, the amount of sublethal damage that can be repaired between fractional exposures declines with increasing LET of the radiation. Furthermore, the relative biological effectiveness (RBE) of radiation increases with increasing LET and decreases with decreasing dose or dose fraction for a given LET.

Death of large numbers of cells within an organism, as in the case of severe exposure to X or gamma rays, usually results in the death of the organism itself. The radiation will kill fast growing cells such as the white blood cells and the person usually dies of secondary infection within days.

5.2.2 The Hazard Presented by Specific Radiations

5.2.2.1 Alpha radiation

Alpha radiation does not present a significant external radiation hazard, because it only has a range of several centimetres in air and is stopped by the outer layers of human skin. However, if taken inside the body alpha radiation presents the most serious internal radiation hazard of all because of its propensity for intense ionisation in a local area of tissue.

Nuclei that emit alpha particles are heavy nuclei. The chemical properties of such elements dictate that they are bone seekers and that they have long biological half lives. Consequently, many alpha emitters have been associated with bone cancer.

5.2.2.2 Beta radiation

Beta radiation rarely presents a large external hazard unless it is highly energetic (e.g. Phosphorous-32) and close to the skin, in which case it may cause injury to the outer layers of skin. If taken within the body beta radiation represents a significant internal hazard due to its ability to ionise the tissue in a localised area.

5.2.2.3 Gamma, X and neutron radiation

Gamma, X and neutron radiation are the most serious as external radiation hazards due to their ability to traverse large distances. They may cause injury to all areas of the body without much localisation. They do not represent the same internal radiation threat as particulate radiations because most of the energy may pass through the body without causing any damage.

5.2.3 The Relative Effects of Specific Radiations

Radiation weighting factors

The ICRP define radiation weighting factors (W_R) to express the relative biological effectiveness of different kinds of ionising radiation. These were formerly known as the "Quality Factors". The radiation weighting factor is related to LET and RBE. The ICRP recommend the radiation weighting factors given in Table 2.

Type of particle	**Energy range**	**W_R**
X and gamma rays	All energies	1
Beta particles	All energies	1
Neutrons[1] thermal:	< 10 keV	5
	10 keV to 100 keV	10
fast:	> 100 keV to 2	20
		10
	> 2 MeV to 20	5
Alpha particles, fission fragments, heavy nuclei	> 20 MeV	20

Table 2: Radiation weighting factors for various types and energies of radiation

The ICRP define RBE as the inverse ratio of the absorbed doses producing the same degree of a defined biological end-point. In simple terms this is an index of the relative danger of different types of ionising radiation.

LET denotes the average energy imparted to tissue per unit length along the path of travel of an entity of ionising radiation.

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[1] The reason for the decline in W_R for highly energetic neutrons is due to their change in ability to ionise locally. i.e. Thermal neutrons behave like alpha particles and fast neutrons behave like gamma particles.

5.3 Susceptibility to the Effects of Ionising Radiation

5.3.1 Tissue Susceptibility

Different tissues within the body show differing susceptibilities to the effects of ionising radiation. The ICRP have summarised this information in terms of the tissue weighting factors (W_T) given in Table 3. The tissue weighting factor represents the relative contribution of a particular organ or tissue to the total detriment (see the definition of detriment in section 8) due to the effects of uniform irradiation of the whole body. It is considered that those organs or tissues with the highest W_T values have the greatest susceptibility to ionising radiation.

ICRP Tissue Weighting Factors		
Tissue or organ	**W_T**	**Comment**
gonads	0.20	Most sensitive
bone marrow (red)	0.12	
colon	0.12	
lung	0.12	
stomach	0.12	
bladder	0.05	
breast	0.05	
liver	0.05	
oesophagus	0.05	
thyroid	0.05	
skin	0.01	Least sensitive
bone surface	0.01	Least sensitive
remainder	0.05	

Table 3: Tissue weighting factors for various human tissues

Fast growth rate is the underlying reason why cancerous cells, white blood cells (bone marrow), the gonads and the foetus are the most susceptible to the adverse effects of ionising radiation.

5.3.2 The Susceptibility of Individuals

5.3.2.1 Radiation induced non-cancer effects

There is a wide range of susceptibilities observed amongst individuals to the effects of ionising radiation. Age and state of health are major factors that affect the susceptibility of most individuals. It has been documented that the elderly, the young and the sick are the most susceptible to the deleterious effects of exposure to ionising radiation.

5.3.2.2 Radiation induced cancers

- **Age**: Susceptibility to leukaemia is greatest during prenatal development, childhood and old age. It is reduced during adolescence and adult life. Cancer of the thyroid gland is more likely in children than in adolescents and adults. Cancer of the female breast is most likely in childhood and adolescence than at any stage of adult life. The probability of induction of skeletal cancer appears no more likely in children than in adults. In other type of cancers it appears that the probability of effect is the same for all people over 10 years of age.

- **Sex**: The development of radiation induced breast cancer occurs almost exclusively in women because of the known role of hormonal stimulation of the mammary gland in development of any female breast cancer. Radiation induced thyroid cancers also occur more frequently in females by a factor of approximately three. The exact reason for this is unknown. For cancers of other sites, the risk appears to be less pronounced but still greater for females than for males. The exception to this is leukaemia where males are more susceptible. Overall, the excess risk of radiation-induced cancer is about twenty percent higher in females than in males.

- **Disease factors**: The genetic diseases listed in Table 4 have been suggested as increasing the susceptibility to certain radiation-induced cancers although the links are not well established.

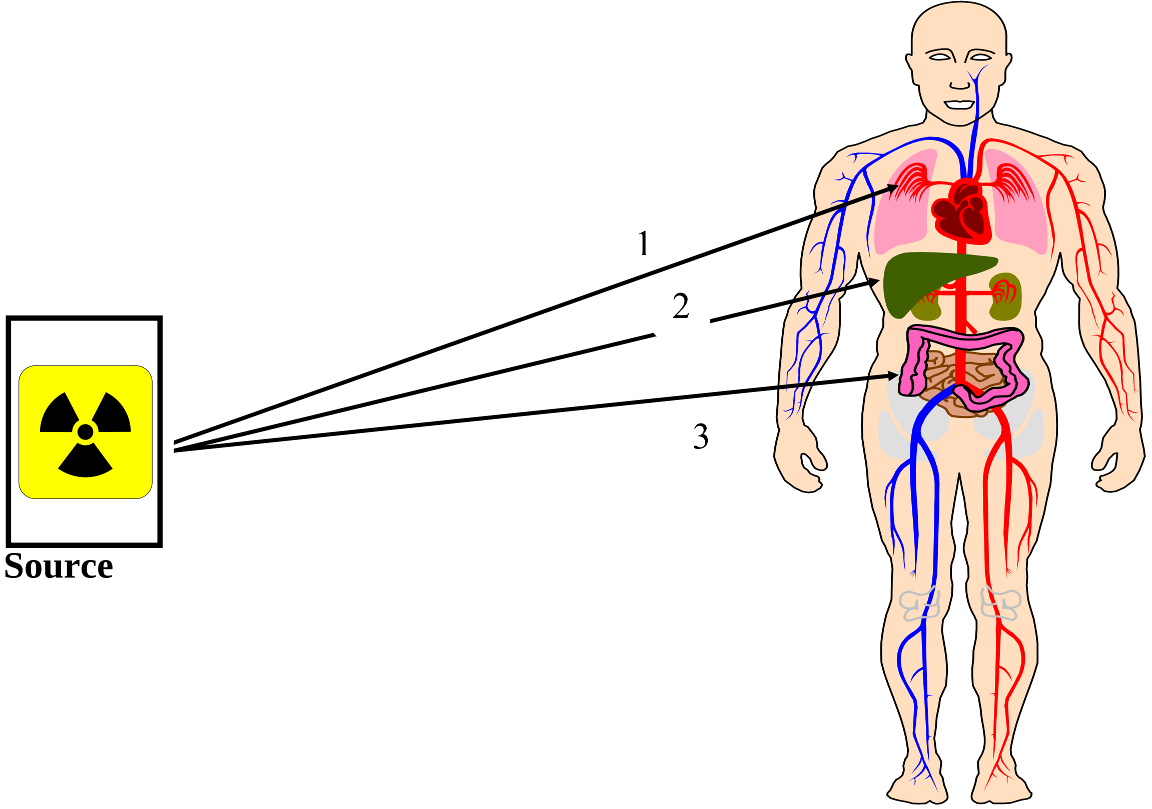
Genetic disease	**Radiation induced disease**
Familial retinoblastoma	Bone cancer
Heterozygosity for the ataxia telangiectasis gene	Breast cancer
Naevoid basal cell carcinoma syndrome	Skin cancer

Table 4: Genetic diseases that may be related to radiation induced disease

- **Other carcinogens and co-factors**: Certain cancer treatment drugs and ultraviolet light are known to increase the probability of cancer when exposure to both ionising radiation and the carcinogen or co-factor has occurred, whether concurrent or not. The combined effects of cigarette smoking and radiation - induced lung cancer results in an increase in the probability of cancer when compared with exposure to only one of these factors.

5.4 Quantification of Ionising Radiation Dose

For the purposes of quantifying the dose of ionising radiation on living tissues, it is useful to consider the following diagram:



SOURCE of ionising radiation

EMISSION of ionising radiation that results in exposure

PERSON absorbs a **TOTAL DOSE** that is distributed as small doses in each organ:

organ 1	**dose 1**
organ 2	**dose 2**
organ 3	**dose 3**

Figure 18: The relationship between source, emission and dose

A source of ionising radiation may emit radiation that varies in quantity with time and space. This is called an EMISSION. The part of the emission that contacts the person exposed to ionising radiation is the EXPOSURE. Exposure is defined only for X-Rays and Gamma Rays with energies up to 3 MeV. The SI Unit is the Coulomb per Kilogram (Ckg^{-1}).

When a material is exposed to radiation, it will absorb radiation energy. The effect depends on the *Energy absorbed per unit mass of the material;* this is the ABSORBED DOSE (D). The SI Unit of Absorbed Dose is Joule per kilogram (Jkg^{-1}), this is called the Gray (G).

Absorbed Dose is used for all kinds of ionising radiation. The effect of ionising radiation on a biological system depends not only on the Dose but also on the kind of radiation and its energy. This difference in effect is taken account of by using the *Radiation Weighting Factor* (W_R). The values of the radiation weighting factor relate to the radiation incident on the body, or for internal sources, emitted from the source, (see table 2 for the values of radiation weighting factors). A good indication of the average biological damage caused by radiation is the EQUIVALENT DOSE (H_T). The unit of Equivalent dose is given the name SIEVERT (Sv) and is Joule per kilogram (Jkg^{-1}).

$$\mathbf{H_T = W_R \, . \, D \ \ (Sievert)}$$

The Gray is determined solely by physical factors whereas the Sievert is combines both physical and biological factors.

The dose calculated for the whole body is "EFFECTIVE DOSE" (E). Effective dose is the sum of the weighted equivalent doses in all tissues and all organs of the body of a single person (see table 3 for tissue weighting factors).

$$\mathbf{E = \Sigma W_T \, . \, H_T \quad (Sievert)}$$

In evaluating the hazard posed by a radioactive source, we therefore need to calculate the **absorbed dose (D)**. From this can be calculated the **equivalent dose (H_T)** in each organ and tissue in the body and from this can be calculated the whole body **effective dose (E).**

5.4.1 Summary of Doses & Units

- Exposure: The amount of radiation reaching a person or thing.
  Defined only for X or γ- Rays, E< 3MeV.
  Unit: COULOMB/ KILOGRAM.

- Absorbed Dose (D) : Energy absorbed per unit mass of material;
  depends on type of radiation. Calls for a radiation weighting factor (W_R).
  Unit: JOULE/ KILOGRAM.

- Equivalent Dose (H_T) :Average biological damage caused by radiation.
  Depends on radiation weighting factor: $H_T = W_R \times D$.
  Units: JOULE/ KILOGRAM . Called SIEVERT.

- Effective Dose (E): The tissue weighted equivalent dose for each tissue.
  Depends on tissue weighting factor W_T : $E = W_T \times H_T$.
  Units: JOULE/KILOGRAM. Also Called SIEVERT.
  Can also have EFFECTIVE BODY DOSE: $E = \sum W_T \times H_T$

5.4.2 Calculated Dose Assessment

It is sometimes useful to calculate a (predicted) dose. This could be useful in determining the type and thickness of shielding required. The calculation could be also used to give a rough estimate of the dose should a radioisotope be ingested.
These calculations are only approximate, as a number of assumptions must be made.

- The source is monoenergetic.
- The source has point geometry.
- The radiation is not attenuated through the air or tissue.
- There is no self absorption by the source material.

5.4.2.1 Internal Sources

Internal absorbed Dose rate for Particles - α, β

Absorbed dose rate for organ = $\frac{14A\,(U_{av1} + U_{av2} + ...)}{M}$ µGy/day.

Where: A = activity (kBq)
U_{av} = α energy, or ave β energy (MeV)
M = mass of organ (kg)

Note: For betas, U_{av} = approx 1/3 U_{max}

Internal absorbed dose rate for photons - γ

Calculations are complicated because only a fraction of the gamma energy is deposited within the body. This is the reason that gamma sources are generally less hazardous than alpha or beta emitters when they get into the body.

5.4.2.2 External sources.

Absorbed dose rate for beta particles - β

$$\text{Absorbed dose rate} = \frac{1.5\ A\ (U_{max1} + U_{max2} + ...)}{r^2}\quad \mu\text{Gy h}^{-1}$$

Where A = activity (Mbq)
U_{max} = maximum β particle energy (MeV)
r = distance from source (m)

Note: The above derived expression is an approximation and provides a useful estimate of hazard potential.

Absorbed dose rate for photons - γ, X, Bremsstrahlung

$$\text{Absorbed dose rate} = \frac{4.6\ A\ (U_1\ \mu_{enm1} + U_2\ \mu_{enm2} + ...)}{r^2}\quad \mu\text{Gyh}^{-1}$$

Where A = activity (MBq)
U = Photon energy (MeV)
r = distance from source (m)
μ_{enm1} = mass energy absorption coefficient (cm^2g^{-1}) of the matter for photon energy U_1

These calculations have already been done for many radionuclides. Values are available in tables eg AS2243.4, Table A3 and are listed as gamma dose rates per Gbq at 1 metre.

6. THE BIOLOGICAL EFFECTS OF IONISING RADIATION

6.1 Categorisation of the Effects of Exposure to Ionising Radiation

6.1.1 The Individual Who is Affected

6.1.1.1 Somatic effects

Somatic effects are a result of personal exposure to ionising radiation and are a direct manifestation of cell death, blocked or delayed cell division or mutation of genetic material. Somatic effects may be further divided into "early" and "late" effects.

- **Early effects:** Early effects are those that occur immediately after to a few weeks after an acute exposure to ionising radiation. An early effect may be permanent or temporary. The effects are usually due to a major depletion in cell populations; particularly in the more susceptible organs. All somatic early effects are considered to be deterministic (See Section 6.1.2.2).

- **Late effects:** Late effects are those that arise either a long time after a single acute exposure, or during the latter part of a course of chronic exposure. A late effect may be permanent or temporary.

6.1.1.2 Hereditary effects

Hereditary effects appear in the first- and later-generation progeny of the exposed individual, and are caused by alteration of the genetic material of the exposed individual. Hereditary effects caused by exposure to ionising radiation are considered to be stochastic (See Section 6.1.2.1).

6.1.2 The Dependence of the Dose on Threshold

6.1.2.1 Stochastic effects

The probability of an ill-effect on the body occurring is a function of dose without threshold. In other words, the higher the dose of radiation, the greater the likelihood that the effect will occur. The severity of the effect will be constant whatever the dose.

6.1.2.2 Deterministic effects

Deterministic effects were previously termed "non-stochastic". The severity of an ill-effect is a function of dose with threshold. In other words, the higher the dose above a certain level (which represents the killing off of sufficient cells for the effect to be discernible), the greater the severity of the effect that will occur.

6.2 The Effects of Ionising Radiation on the Human Body

6.2.1 Whole Body Exposure

6.2.1.1 Radiation sickness

An acute dose of approximately 1Gy may result in nausea, vomiting, rapid pulse and fever, a few hours after the exposure. This is the direct result of damage to cells lining the intestine. This is a somatic, early, deterministic effect.

6.2.1.2 Death

It is accepted that acute doses of ionising radiation above 2Gy have a reasonable probability of early death for the individual irradiated. A dose of 3-10Gy results in the victim suffering severe depletion of white blood cells and usually dying of secondary infection within a few weeks. The lethal dose to 50% of a heterogeneous population, 60 days after dosing, is considered to be 3-5Gy.

Doses of 10-50Gy result in a survival time a few days in the majority of cases. The cause of death is usually dehydration and massive bacterial invasion due to the damage sustained by the intestinal lining. Survivors of doses in this range may face long-term complications such as fibrosis, stricture, intestinal perforation and fistula formation.

Doses in excess of 50Gy result in death within a few hours due to damage to central nervous system tissue. Death in this manner is a somatic, acute, deterministic effect.

6.2.1.3 Cancer

This may occur in almost any organ in the body and its initial location is dependent on the type of radiation, the isotope and the area of the body that is exposed. The mechanism of cancer induction is believed to be a direct result of the ionising potential of radiation.

The probability of inducing cancer with a set low to medium dose of low LET radiation is reduced as the dose is fractionated or protracted. Presumably, this is because a great proportion of the damage is sublethal and the body can repair this prior to the next irradiation. On the other hand, the probability of cancer with the same set dose of high LET radiation stays constant or increases as the dose is protracted or fractionated. In this case, there will be a lesser proportion of sublethal damage that can be repaired prior to each irradiation of a given dose than with low LET radiation. (See also Section 5.2.1).

Radiation induced cancer is rarely distinguishable from cancers that are due to other factors, except perhaps in the case of thyroid cancer where the individual is known to have had a high exposure to iodine isotopes. The main examples of cancers that may be induced by exposure to ionising radiation are shown in Table 5.

Cancer	**Tissue at risk**	**Examples of "high" risk populations**
Leukaemia	Red bone marrow	Children atomic bomb survivors
Lung Cancer	Lung	Uranium mine workers
Thyroid cancer	Thyroid	Users of iodine-125
Bone sarcoma	Cells on bone surface	Women painting luminous clock dials

Table 5: Examples of radiation induced cancers

There is considerable debate in scientific circles about the threshold levels of radiation dose required to cause cancer. The ICRP work on the assumption that the probability of cancer increases linearly with dose. Currently, the assumption of no threshold for radiation induced cancer has been adopted, thus making it a somatic, stochastic and late effect.

6.2.2 The Digestive Tract

6.2.2.1 The liver

The liver is the most sensitive to radiation. Its function is impaired if the whole organ is exposed to a fractionated, therapeutic X ray dose of over 30Gy. Early hepatic injury does not cause interruption of hepatocyte renewal, as this is very slow. A large dose to most of the organ may kill a sufficient number of hepatocytes and cause liver failure (an early, somatic, deterministic effect).

Lower doses may cause damage to the hepatocyte genetic material and render the cells incapable of mitotic division. In this way, atrophy and cirrhosis may develop as the liver slowly deteriorates. This is a late, somatic, deterministic effect.

6.2.2.2 The salivary glands

The salivary glands may undergo necrosis, atrophy and fibrosis after 50-70 Gy of fractionated X rays. This is exhibited as an early or late, somatic, deterministic effect resulting in reduced salivary output.

6.2.2.3 The pancreas

The pancreas can withstand up to 70-80 Gy of conventionally fractionated therapeutic X rays before exhibiting damage comparable to the salivary glands. This is an early or late, somatic, deterministic effect.

6.2.3 The Skin

Beta radiation of all energies, and low energy gamma radiation may have deleterious effects on the skin. The effects of high energy gamma and X rays will generally be controlled by dose limits to other organs. Alpha radiation is simply not sufficiently penetrating to damage skin.

6.2.3.1 Erythema

Ionising radiation will cause severe reddening of the skin reflected by dilation of the capillaries after the release of histamine-like substances from injured epithelial cells. The initial reddening may only last several hours but it may be followed 2-4 weeks later by one or more waves of deeper and more prolonged erythema. The threshold for this effect is 3-5 Gy as an acute dose.

The response to ionising radiation of different bodily tissues varies in the following descending order of sensitivity: front of the neck, elbow and the backs of the knees; front surfaces of extremities, chest and abdomen; face (not strongly pigmented); back and top surfaces of extremities; face (strongly pigmented); nape of neck; scalp; and palms and soles. Erythema is considered to be an early, somatic, deterministic effect.

6.2.3.2 Epilation

Temporary epilation (hair removal) may be induced by a single, acute dose of low LET radiation of 3-5 Gy. Permanent epilation may result from a single, acute dose of 7 Gy or 50-60 Gy fractionated over several weeks. Temporary and permanent epilation is an early, somatic, deterministic effect of radiation exposure where the time frame over which the injury is expressed is related to the kinetics of renewal of the epidermal cells.

6.2.3.3 Desquamation and necrosis

The threshold doses required to produce desquamation and necrosis of the epidermal tissue are higher than for erythema, but not well established. The threshold doses increase with fractionation and protraction of exposure. Desquamation and necrosis are early, somatic, deterministic effects of exposure to ionising radiation whose time of appearance is related to the kinetics of turnover of the epidermal cells.

6.2.3.4 Skin atrophy and fibrosis

Skin atrophy and fibrosis are late, somatic, deterministic effects that are not related entirely to the kinetics of replacement of the epidermal cells. Instead, these changes appear to be mainly related to the depletion of fibroblasts and injury to blood vessels in the dermis. Estimates of the dose required to elicit responses of skin atrophy and fibrosis are sketchy but the ICRP put forward an estimate of 10-30 Gy for low LET radiation accumulated over a period of 8-25 years.

6.2.3.5 Skin cancer

Basal cell and squamous cell carcinomas, but not melanoma (the most dangerous of all skin cancers), have been associated with exposure to ionising radiation. The risk of skin cancer is influenced by an individual's exposure to ultraviolet radiation and the degree of pigmentation that their skin possesses. It is known that exposures to the skin in excess of 10 Gy carry a significant excess risk of skin cancer. It is now thought that this risk may be significant down to 1 Gy. Radiation induced skin cancer is a late, somatic, stochastic effect.

6.2.4 Haematopoietic System (blood and blood forming organs)

The threshold of significant depression of the blood forming process for an acute dose, given to the whole bone marrow, is 0.5 Gy. The dose rate threshold for protracted exposure over many years is more than 0.4 Gy per year. The various cells of the haematopoietic system are depleted at different rates. The white blood cells are one of the most sensitive and reach their lowest concentration in the blood after 5 weeks. This effect of depletion is an early, somatic, deterministic effect.

There is a high probability of death if the dose is acute and over 2 Gy and no treatment is given (see section 6.2.1.2).

6.2.5 Cardiovascular System

The heart is not highly radiosensitive. However, a dose of 40 Gy in conventionally fractionated radiotherapy may cause discernible myocardial degeneration. A dose in excess of 60 Gy to the entire heart may lead to death from pericardial effusion, fibrosis or constrictive pericarditis. Vascular damage plays a major part in this late, somatic, deterministic radiation induced injury.

6.2.6 Eye and other Sensory Organs

All sensory organs except the lens of the eye are relatively resistant to the effects of ionising radiation. The middle and inner ear are known to be able to withstand up to 50 Gy of highly fractionated irradiation without any serious effects on hearing. The lens of the eye is prone to developing cataracts after irradiation. Neutrons have been shown to have the greatest RBE in this regard. Cataracts are regarded as a late, somatic, deterministic effect.

The radiation causes breakdown of the dividing cells in the anterior epithelium of the lens. The waste products of this damage collect on the lens of the eye to form the cataract. In the early stages, radiation induced cataracts are distinguishable from cataracts of other origins. Studies indicate that vision-impairing cataracts may be induced by X rays from a dose of 2 Gy as a single, acute exposure or a dose of 8 Gy as an exposure fractionated over months or years. The doses of neutrons required to affect the same changes are considered to be less; 0.5-1 Gy for an acute exposure and 3-5 Gy for an equivalent fractionated exposure. The general threshold that is given to avoid visual impairment in the case of occupational exposures that are highly fractionated and protracted is a maximum of 0.15 Sv per year.

6.2.7 Nervous System

The nervous system is regarded as relatively radioresistant. All effects to the nervous system are late, somatic and deterministic. Functional impairment has been observed in the brain after its irradiation with acute doses above 10 Gy. Necrosis of the brain was not fully apparent until several years after exposures above a threshold of 55 Gy delivered over 5.5 weeks to the whole brain.

Damage to the spinal chord consists of demyelisation and necrosis of the white matter and develops slowly after exposure. The threshold for this type of damage appears to be 30 Gy if the dose is fractionated into 3 Gy increments or 40-50 Gy if the increments are 2 Gy each. The peripheral nerves may be damaged at doses in excess of 60 Gy delivered as conventionally fractionated radiotherapy.

6.2.8 The Reproductive System

The germ cells of both sexes are more highly radiosensitive than other reproductive cells. All effects of sterility on the germ cells are early, somatic and deterministic.

In the testes, spermatogonia are more sensitive than the spermatocytes, spermatids and spermatozoa. Temporary sterility due to a reduced sperm count may be caused by an acute exposure of 0.15 Sv. The count will not increase for several weeks until the spermatogonia are at the maturation stage. An acute dose of 3.5-6 Sv may cause permanent male sterility as the stem cells may be damaged and take years to regenerate. If the dose is highly fractionated or protracted over a period of many years, the threshold for temporary sterility is 0.4 Sv per year, and for permanent sterility it is 2.0 Sv per year.

In the female ovary, the mature oocyte is the most radiosensitive. An acute exposure to both ovaries of 2.5-6 Sv may cause prompt, permanent sterility, as the oocyte is not replaced in the female reproductive cycle. Older women are more sensitive due to their depleted stocks of oocytes. The corresponding threshold for a highly fractionated or protracted exposure over many years is 0.2 Sv per year with an upper dose limit of 6 Sv.

6.2.9 The Urinary Tract

The dose required for significant injury to the organs of the urinary tract is lowest for the kidneys, intermediate for the bladder and highest for the ureters. All the effects are late, somatic and deterministic.

The damage to the kidney appears to involve degeneration of the nephrons and the vasculature leading to degeneration of the renal tubules. This develops over 6-12 months as a result of radiotherapy doses exceeding 10 Gy. At higher doses the damage may be permanent. The tolerance of the bladder is approximately 55-60 Gy fractionated over 4 weeks. Complications of larger doses include; cystitis, ulceration, fibrosis, constriction and urinary obstruction.

6.2.10 The Respiratory System

The alveoli and pulmonary vasculature within the lungs are the most sensitive of the respiratory system. A single acute dose above 10 Gy or 20-30 Gy fractionated over 6-8 weeks may cause a fatal pneumonitis within 2-6 months. Those surviving the early symptoms may later succumb to pulmonary fibrosis. The nasopharynx, pharynx, larynx, trachea and bronchi require doses of at least 30 Gy fractionated into 2 Gy lots to effect conditions such as ulceration, atrophy and fibrosis.

6.2.11 Musculoskeletal System

Mature muscle, bone and cartilage are relatively inert to ionising radiation. All effects on the musculoskeletal system are late, somatic and deterministic. Mature cartilage will tolerate 40 Gy fractionated over 4 weeks or more than 70 Gy fractionated over 10-12 weeks. Mature bone will tolerate 65 Gy fractioned over 6-8 weeks and muscle will tolerate 60 gray in 2 Gy fractions. At doses in excess of these, contraction and delayed healing of muscle may occur and other tissue may have reduced tolerance to subsequent trauma.

Fractured bones that are healing and the musculoskeletal system of children is more susceptible to the effects of ionising radiation. At doses of 1 Gy these tissues may show some retardation of growth. A conventionally fractionated, therapeutic dose of 20 Gy may cause scoliosis, kyphosis or other skeletal disorders.

6.2.12 The Endocrine System

The most sensitive of the endocrine glands is the thyroid, particularly in children. Functional thyroid damage ensues when the whole of the organ is exposed to doses in excess of 25-30 Gy fractionated over 30 days. In children hypothyroidism and retarded growth have been observed at lower radiation doses. For permanent functional depression of the adult pituitary and adrenal gland the threshold doses are 45 and 65 Gy respectively, of fractionated irradiation.

As an endocrine target organ the female breast is particularly sensitive during development. The development may be impaired if exposed to doses in excess of 10 Gy given as conventional, fractionated, therapeutic X rays. These effects are late, somatic, and deterministic.

6.3 The Effects of Ionising Radiation on the Unborn Child

The effects of ionising radiation on the unborn child depend almost entirely on the stage of development. Up to 3 weeks after conception, the number of cells is small and they are not yet specialised. A small, acute radiation exposure (such as 0.1 Gy) may be an undetectable death and purging of the embryo. Higher doses during later stages of the pregnancy may produce the same effect.

During the third week, the period of organogenesis begins with the formation of the nervous system and heart. From this time until the end of major organogenesis at start of the ninth week after conception, the embryo is vulnerable to malformations in any organ under development at the time of exposure. Such malformations are late, somatic, deterministic effects and are estimated to have a threshold of 0.1 Gy in human beings. Growth disturbances may be the predominant effect during the latter stages of pregnancy, although the thresholds for these are not well known.

Throughout the period commencing 3 weeks after conception and ending at birth, the unborn child may be susceptible to an increased probability of cancers or leukaemias, expressed in the first decade of life. Estimates of the doses required to increase this probability are unavailable at this time. This form of cancer is a late, somatic, stochastic effect.

During this same period, the brain of the unborn child appears to be particularly vulnerable. Data from Hiroshima and Nagasaki indicates that IQ may be affected (a direct relationship with increasing dose). A coefficient of 30 IQ points may be lost per Sv of exposure by the unborn child in the period from 8 to 15 weeks after conception. During this period, the excess probability of severe mental retardation is calculated at 0.4 per 1 Sv of exposure *in utero*. The brain appears to be less susceptible during the period of 16-25 weeks; the excess probability is reduced to 0.1 per Sv of exposure. After 25 weeks, the probability of severe mental retardation appears to be within the normal statistical range. Effects on the brain are regarded as late, somatic and deterministic.

6.4 The Effects of Ionising Radiation on Later Generations

Nearly all disease is to some extent genetic and to some extent environmental. At the genetic end of the spectrum are conditions that relate almost entirely to chromosomal anomalies or gene mutations (Mendelian conditions). These tend to be rare. In the middle of the spectrum are conditions that are more common and tend to cluster in families. These are known as "partially genetic" or "multifactorial". At the environmental end of the spectrum is infectious disease. Mendelian, chromosomal and partially genetic disorders are the subject of the remainder of this section.

Mendelian conditions are subdivided into four groups, listed in Table 6. It should be noted that "dominant" conditions usually occur in the first generation progeny of the irradiated person. "Recessive" conditions may occur in later generations if inherited from both parents. "X-linked" refers to a mutated gene on an X (female) chromosome.

Mendelian disorders	
Condition	Examples
Autosomal dominants	**Appear in adult life:** Huntington's disease, polycystic kidney disease, multiple polyposis, cerebellar ataxia and myotonomic dystrophy **Onset during childhood:** Achondroplasia, Apert syndrome, bilateral aniduria, Crouzon syndrome and osteogenesis imperfecta type I.
Autosomal recessives	**Onset at birth or childhood:** Cystic fibrosis, phenylketonuria and adrenal hyperplasia.
X-linked	**Onset at birth or childhood:** Duchenne and Becker muscular dystrophy, haemophilia A, fragile-X associated mental retardation and X-linked retinitis pigmentosa.
Chromosomal anomalies	**Onset at birth or early childhood:** Down syndrome and Cri du chat syndrome due to deletion of the short arm of chromosome 5.

Table 6: Examples of Mendelian disorders

The multifactorial diseases may be divided into congenital abnormalities and common disorders of adult life. They are listed in Table 7. The causes of such diseases are many and varied. The proportion of genetic factor versus environmental factor is usually variable and unknown. Ionising radiation is only one of many agents that may be partially or wholly responsible for precipitating a genetic disease.

Multifactorial disorders	
Condition	**Examples**
Congenital abnormalities	**Onset at birth or early childhood:** Neural tube defects, congenital heart defects, pyloric stenosis, cleft lip, cleft palate and undescended testes
Common disorders of adult life	**Appear in adult life:** Schizophrenia, multiple sclerosis, epilepsy, acute myocardial infarction, systemic lupus erythematosus, glaucoma, diabetes mellitus, rheumatoid arthritis, asthma, varicose veins of the lower extremities, allergic rhinitis and atopic dermatitis.

Table 7: Examples of multifactorial disorders

7. SOURCES OF EXPOSURE TO IONISING RADIATION

7.1 Man Made Sources of Ionising Radiation

7.1.1 Irradiating Apparatus

All irradiating apparatus poses an external hazard to any subject being irradiated. They are usually in the form of an X ray machine.

7.1.1.1 X ray machines

These are the most commonly used irradiating apparatus. They are in wide use at Monash University for many of the following applications:

- **Diagnostic radiology:** Low and medium energy X rays are used for imaging parts of the body for medical, teaching research and veterinary purposes. Diagnostic radiology procedures are performed by Monash University staff in many departments. Diagnostic radiology is considered to represent the largest single source of radiation exposure for most members of the Australian public.

  Persons who are subjected to diagnostic radiology may receive doses of ionising radiation in the orders of magnitude shown in Figure 19 (on the following page).

- **Therapeutic radiology (radiotherapy):** Higher energy X rays may be used for the medical treatment of certain conditions such as cancer. At Monash University therapeutic radiology finds application as part of research using humans or animals as subjects. Such experiments are carefully controlled and examined by the Department of Human Services and the RPO prior to their beginning. Persons receiving radiotherapy treatment to kill malignant tumours may receive doses in the order of tens of gray to a localised area from a cobalt-60 gamma or X ray source.

- **Industrial radiography**: High energy X rays are used in industrial radiography for examining artefacts such as coins. Invariably exposure from these sources of ionising radiation will vary in magnitude and will be due to accidents.

Means of Exposure	**Size of a single dose**
Thyroid scan using iodine-131 (g)	40 mSv
Radiation worker 1 year exposure limit	20 mSv
Radiotherapy for a malignant abscess using gallium-67 (g)	18 mSv
Brain scan using technicium-99m	5 mSv
Pelvic X ray	1.5 mSv
Member of the public 1 year exposure limit	1 mSv
Thyroid scan using technicium-99m	600 µSv
Exposure from current chromium-51 (g) from stores in the blood	400 µSv
Exposure from current cobalt-58 (g)from Vitamin B12 absorption	300 µSv
Dental X ray	100 µSv
Chest X ray	50 µSv

Figure 19: Approximate sizes of radiation doses for various medical procedures

7.1.1.2 X ray fluorescence and diffraction analysis

These types of instruments are generally used for research for examining crystal structure. They produce high energy X rays and can be used in alloy analysis, chemical plating analysis as well as general chemical analysis. The technique depends on the unique characteristics of emission of a particular element when impinged on by an X ray beam.

7.1.1.3 Miscellaneous equipment

Examples are electron microscopes, cathode ray tubes, high voltage electronic rectifiers and television screens, which all produce small amounts of low energy X radiation. These are generally considered to constitute a minor external radiation hazard. One example of the magnitude of such exposure is that of watching three hours of colour television per day at a normal distance. This gives an exposure of approximately 5 mSv per year.

7.1.2 Sealed Sources

A sealed source by definition is any radioactive material that is firmly contained so as to prevent dispersion under normal conditions of handling or storage. Sealed sources usually constitute an external radiation hazard. A leaking sealed source can pose an internal radiation hazard if contamination is spread. Some examples of the sources held by Monash University, their activities and their uses are listed in Table 8.

Source	**Activity**	**Use**
Cobalt-57	1110 MBq	Mossbauer research
Caesium-137	6 GBq	Research involving the biological effects of radiation
Americium-241	7.4 GBq	Teaching
Carbon-14	37 kBq	External calibration of liquid scintillation system.
Iodine-129	31 kBq	Gamma reference source for equipment
Barium-133	695 kBq	External calibration of equipment

Table 8: Examples of sealed sources at Monash University

7.1.3 Sealed Source Apparatus

Sealed source apparatus contains one or more sealed radioactive sources installed in a housing that prevents or minimises exposure of the users to the source. They usually constitute a minor external radiation hazard when the housing of the source is in good condition. It is violation of this housing during maintenance or transport that generally leads to exposures. Examples of sealed source apparatus used at Monash University are the radium-226 sources commonly found in beta counters and the nickel-63 sources used within the electron capture detectors of gas chromatographs. Some of these sources are listed in Table 9.

Source	Activity	Use
Radium-226	370 kBq	Calibration of a beta counter
Europium-152	740 kBq	Calibration of a beta counter
Nickel-63	555 MBq	Calibration of an electron capture detector of a gas chromatograph
Iron-55	370 kBq	Source of soft X rays in an instrumental analysis

Table 9: Examples of sealed source apparatus at Monash University

7.1.4 Unsealed Radioactive Material

Unsealed sources are not contained in the same manner as a sealed source. They will readily produce contamination if handled inexpertly. Unsealed radioactive material can be a major external and internal radiation hazard. A wide variety of unsealed radioactive nuclides are used for research at the various sites of Monash University. Some of these are listed in Table 10.

Radionuclide	Typical use/carrier material
Iodine-125	Carrier free or in iodinated peptides
Sulphur-35	Steroids, sulphuric acid
Hydrogen-3	Steroids, prostaglandins, peptides
Carbon-14	Steroids, carbohydrates
Phosphorus-32	Fatty acids, mRNA
Calcium-45	Calcium chloride
Phosphorus-33	Inorganic phosphate, ATP

Table 10: Some examples of sealed sources at Monash University

7.1.5 Radioactive Fallout

The radiation dose Australians receive due to radioactive fallout is approximately 3 μSv/yr. This may be directly attributed to mankind's activities with radioactive materials such as; atomic bomb use and testing, accidents in nuclear power plants and incorrect disposal of nuclear material which may become airborne. Some of the major radioisotopes involved are plutonium-239, carbon-14, strontium-90 and caesium-137.

7.2 Natural Sources of Ionising Radiation

7.2.1 Cosmic Radiation

Cosmic radiation comes from the sun and its intensity varies with altitude. Table 11 gives estimates of radiation exposures due to cosmic rays for people situated at various altitudes:

Geographical location	**Exposure due to cosmic radiation**
Sydney (sea level)	300 μSv per year
Canberra (580 metres above sea level)	400 μSv per year
Katoomba (1000 metres above sea level)	500 μSv per year
Wyoming USA (2600 metres above sea level)	1300 μSv per year
Perth to Sydney and return on a commercial flight (10 000 metres above sea level)	30 μSv per year

Table 11: Approximate exposure to cosmic radiation at various geographical locations

Primary cosmic radiation also interacts with other atmospheric materials to produce secondary cosmic radiation in the form of radionuclides such as tritium, beryllium-7, carbon-14 and sodium-22.

7.2.2 Terrestrial Radiation

Exposure from terrestrial radiation comes mainly from the ground and building materials. Radioisotopes such as potassium-40, uranium-23 and thorium-232 have half-lives in the order of 10^9 years and thus emit radiation for a long time. They are common constituents of soils and building materials.

All people are exposed to various forms of natural radiation. Exposures can vary from 200 - 25,000 μSv per annum, depending on the soil and rock composition. In most parts of Australia, radiation from terrestrial sources is estimated to be 500 μSv per annum. In comparison, in some parts of India an exposure rate of 25,000 μSv per annum has been documented; this has been attributed to the high thorium content of the soil.

Another isotope important as a source of terrestrial radiation exposure is radon-222. In contrast to other natural isotopes, it has a short half-life. It is found in high concentrations in some soils, and may find its way into water streams and building materials. It is often concentrated in houses specifically built for colder climates (eg USA). Some examples of typical exposures to terrestrial sources of radiation are given in Table 12.

Source	Exposure
Living in a brick or concrete house	1000 µSv per year
Consuming an average quantity of water, food and air	250 µSv per year

Table 12: Approximate exposures due to terrestrial radiation

7.2.3 Overall Exposure to Natural Sources of Radiation

The average natural radiation exposure (cosmic plus terrestrial) for an Australian is about 2000µSv or 10% of the current occupational whole body dose limit. There are other sources of non-occupational exposure to radiation.

The natural, terrestrial, medical, fallout and miscellaneous sources of radiation exposure all add up to give the average Australian who does not work with ionising radiation an exposure of approximately 2700 µSv per annum.

8. THE LEVEL OF RISK IN RELATION TO THE USE OF IONISING RADIATION

8.1 The Concept of Risk

The ICRP have defined "risk" as a concept that includes probability of death and contributions from other factors such as illness, hereditary disease, risks to the foetus, economic losses, anxiety and other societal impacts. The probability of death aspect of risk is far more quantifiable than the other factors. As a consequence the ICRP only quantifies, in terms of numerical probabilities, the magnitude of risk that some of the factors other than death, present.

The ICRP have not numerically defined an acceptable level of risk in their latest publication (ICRP 60) due to the immense social difficulties in doing so. Previous dose limits (ICRP 26) were based on an annual occupational death probability of 10^{-3} as being just acceptable. This is no longer considered to be the case.

8.2 The Concept of Detriment

The ICRP defines a quantity known as the "total detriment". Total detriment is the mathematical expectation of total harm that would eventually be experienced by an exposed group and its descendants as a result of the group's exposure to ionising radiation. Total detriment is a function of the probability and severity of effects. Total detriment is made up of "health detriment" (effects on health) and "other detriment" such as the need to restrict the use of some geographical areas or products. In giving mathematical probabilities for radiation induced effects the ICRP has considered only health detriment.

The health detriment can be subdivided into four different components; fatal cancer in any organ, loss of a segment of life due to fatal cancer, morbidity resulting from induced non-fatal cancers and the risk of serious hereditary disease in later generations.

8.3 Probabilities of Deleterious Effects

8.3.1 Ionising Radiation Exposure

8.3.1.1 Low LET radiation

The incidence of mental effects for low LET radiation exposure to the unborn child are listed below in table 13. The incidence of hereditary effects due to low LET radiation exposure are listed in table 14. Both of these tables provide the data as effects per million people per mSv of exposure

Mental effect (per 10^6 live births per mSv of exposure)				
Effect	**Population Exposed**	**Exposure period**	**Exposure modes**	**No cases**
Severe mental retardation	**Unborn**	8-15 weeks after conception	High dose or dose rate	400
		16-25 weeks after conception	High dose or dose rate	100

Table 13: Incidence of mental effects due to low LET radiation

Severe hereditary effects (per 10^6 per mSv of exposure)				
Effect	**Population Exposed**	**Exposure period**	**Exposure modes**	**No cases**
Mendelian, chromosomal and multifactorial	**Whole population**	All generations	Low dose/dose rate	10
Mendelian, chromosomal and multifactorial	**Working population**	All generations	Low dose/dose rate	6

Table 14: Incidence of severe hereditary effects due to low LET radiation

8.3.1.2 High LET radiation

- *Cancer and hereditary effects*

The probabilities would be the same as those for low LET radiation except that the dose required to elicit the same response will be higher in line with the value of W_R. For example, a 1 mSv dose of alpha radiation at the tissue would be expected to have the same probability of a certain (defined) deleterious effect as a 4 mSv dose of beta, gamma or X rays.

Note that the increased chance of fatal cancer for a member of the public over a radiation worker is indicative of the good health of people in the working population versus those in the general population.

8.3.2 The Risk of Radiation Work Versus Other Work

In order to compare the annual detriment between a radiation worker population and a non-radiation worker population the variables chosen for the radiation worker population were as follows (ICRP 45):

- Equal numbers of men and women
- No restriction on women due to pregnancy
- Annual dose of 2 mSv (this is an internationally representative average)
- Fatal accident rate (due to non-radiation factors) of 25 x 10^{-6} per year. This is representative of a "safer" manufacturing industry.

The total detriment for the radiation worker population was equal to that for a non-radiation worker population that had a fatal accident rate of 35 - 50 x 10^{-6} per year. In other workers the 2 mSv of occupational exposure to ionising radiation encountered by radiation workers had added between 10 and 25 fatalities per million radiation workers at risk. This fatality rate is still less than many non-radiation industries:

e.g.

Industry	***Fatality rate (per 10^6 workers per year)***
Ship Building	*113*
Metal Manufacture	*118*
Coal & Petroleum Products	*148*

8.4 Levels of Ionising Radiation Exposure

The Australian Radiation Laboratory (ARL) compiles an annual summary of the average occupational exposures of Australian radiation workers including those at Monash University. The following tables are summaries of that data for 1991.

Operation	Highest reading (μSv)	Range of average annual exposure*
Diagnostic radiology	133.5	7-395
Radiotherapy	482.2	10-876
Nuclear medicine/pathology	426.8	4-1,718
Industry	244.2	8-1,670
Mining	947.5	147-1,831
Government research	53.4	10-66
Medical/Veterinary research	46.3	1-78
Industry research	49.3	12-137
Secondary/tertiary education	44.1	4-255

**The range is a range of average values for each occupation.*

Table15: Whole Body Exposure to Alpha, Beta, Gamma and X Rays (Data from ARL on occupational radiation exposures in Australia

Operation	**Highest reading (μSv)**	**Range of average annual exposure***
Radiotherapy	3,228.6	1,590-5,550
Nuclear medicine/Pathology	9,105.5	630-15,080
Industry	2,170.5	380-5,150
Research	1,008.6	520-10,170
Education	1,452.6	1,280-2,330

* *The range is a range of average values for each occupation.*

Table 16: Extremity Exposure to Alpha, Beta, Gamma and X Rays (Data from ARL on occupational radiation exposures in Australia)

9. STATUTORY REQUIREMENTS

9.1 Commonwealth Recommendations

In Australia, responsibility for ionising radiation safety lies with the state and territory governments who have enacted law to control the use of ionising radiation sources. The recommendations of the NH&MRC have been adopted by the state and territory governments in most cases.

9.2 The Victorian Requirements

Monash University follows the directives of the Victorian State Government in relation to ionising radiation. The Department of Health and Community Services, Victoria is the administering body for the Health (Radiation Safety) Regulations 1994. A large, but not exhaustive list of statutory documentation connected with ionising radiation including; Australian Standards, codes of practice and guidelines is to be found in Appendix B.

9.2.1 Legislative Requirements

- Division 2AA of the Health Act which invokes the radiation safety regulations.

- The Health (Radiation Safety) Regulations 1994, subsequent amendments and any documents issued pursuant to or directly referenced within these regulations.

- The Occupational Health and Safety Act 1985. This Act forces a duty of care upon all employers and a duty of responsibility on all employees. It requires an employer to provide and maintain so far as is practicable, for employees, a working environment that is safe and without risks to health. An employee is required to take reasonable care in performance of duties and is prohibited from any wilful or reckless actions that may place themselves or other persons at risk.

- The Nuclear Non-Proliferation (Safeguards) Act 1987 and Regulations apply to the storage and use of "nuclear material" (having special meaning within this Act and Regulations). e.g. Enriched uranium and heavy water.

9.2.2 Advisory Documentation

Australian Standards, codes of practice and other guidelines produced by expert bodies such as the NH&MRC and Worksafe are all examples recommendations that are not legally binding in their own right although some are adopted under the Health (Radiation Safety) Regulations 1994.

The recommendations within Australian Standards, codes of practice and other guidelines are often used very effectively as evidence in the courts to prove negligence in a common law claim or non-compliance with the Health (Radiation Safety) Regulations 1994.

9.3 Major Requirements of the Health (Radiation Safety) Regulations, 1994

These regulations are the cornerstone of radiation safety in Victoria. A discussion of every aspect of the current Regulations is beyond the scope of this document. However, some of the major requirements in relation to the University's use of ionising radiation are set out below.

9.3.1 Licences

9.3.1.1 General

Monash University rules for licensing are discussed in Section 16 of the Policy Statement.

Any person carrying out work involving ionising radiation must be licensed to do so or must be working under the direction and supervision of a person holding such a license (in Monash's case the RPO). Persons who are employed or undertake courses of study at Monash may function under the umbrella coverage of licences held by the University’s various sites.

9.3.1.2 Licensing of individuals

Dedicated operator licences are required for individual persons who are practising radiologists, diagnostic medical radiographers, radiation oncologists, medical therapy radiographers, nuclear medicine specialists, nuclear medicine technologists, general medical practitioners, dentists, chiropractors, dermatologists, ophthalmologists, other medical specialists, paramedics (for the purposes of undertaking limited radiographic procedures), persons who test radiation safety of ionising radiation apparatus and sealed radio-active sources, servicemen of ionising radiation apparatus, principal researchers of medical or scientific research involving the administration radiation to humans, veterinary surgeons and industrial radiographers.

Monash University currently holds a site licence for Clayton Campus to carry out research involving the irradiation of human volunteers. However, project approval as well as operators licences are necessary before any work can commence. Operator licences are paid for by the department directly involved in carrying out the research.

9.3.1.3 Licensing by type of ionising radiation source

An organisation or an individual may be licensed for;

- ***irradiating apparatus*** (each apparatus must be registered. Refer to section 9.3.2),
- ***sealed source apparatus*** (each apparatus must be registered. Refer to section 9.3.2),
- ***sealed sources*** (each source must be registered. Refer to section 9.3.2),
- ***unsealed sources*** (Institution licence per site, details of each area used and each isotope must be provided)
- ***research involving the irradiation of human volunteers*** (details of any project must receive separate approval).

9.3.1.4 Monash University's Current Licences

Monash University (represented by the RPO) holds licences for;

Unsealed radioactive sources

These are now required to be held as separate site licences. The conditions of the licences are set out on the certificates of registration and may be obtained on request from the RPO or the DRPO.

- Clayton campus: licence number: 333500057;
- Gippsland campus: licence number: 333500772;
- Caulfield campus: licence number: 333500552;
- Alfred Hospital: licence number: 333500743;
- Box Hill Hospital: licence number: 333500769;
- Monash Medical Centre: 333500811
- Pharmacy College: licence number: Pending renewal
- Research involving human volunteers: 333600177

Monash University Site licences are administered through OHSE and the fees are paid from central funds. The University is required to specify the types of sources and quantities of radiation that are to be held under each licence category. **The conditions of each licence are only valid for as long as this information is correct**. Consequently, it is imperative that people who are increasing their stocks or types of unsealed sources, provide OHSE with complete details prior to their purchase, so that the licences may be kept up to date as required by the regulatory authority.

Sealed source apparatus and sealed sources:

The University is no longer required to hold an Institution licence for sealed source apparatus and sealed sources.

Irradiating apparatus:

The University is no longer required to hold an Institution licence for sealed source apparatus and sealed sources.

9.3.2 Registrations

Monash University rules for registration are discussed in section 16 of the Policy Statement.

Individual ionising radiation sources of any of the following types must be registered.

- Irradiating apparatus.
- Sealed source apparatus.
- Sealed sources.

The responsibility for initial registration, annual re-registration, re-registration after a change of ownership and payment of all costs associated with any changes rests with the owner department. Registration forms are available from the OHSE or the Department of Health and Community Services Victoria. A reminder of re-registration is sent via OHSE to all source owners prior to the due date for annual registration fees. The owner department must provide the RPO with copies of all registration information including the current location of the source or apparatus.

The RPO **must** be notified of any change of location of any X-Ray machine or irradiating apparatus prior to relocation and after the equipment has been installed in its new location so that safety checks can be performed. The Department of Health and Community Services must be promptly notified of any change of ownership or location.

The owner of any registered source of ionising radiation is required to keep the most current registration label affixed to the source at all times. In the case where this is impossible, the registration must be kept by the departmental RSO or deputy RSO.

The Department of Health and Community Services, Victoria has placed conditions on all registrable sources of ionising radiation. These conditions are set out on the certificate of registration for that particular source and must be complied with at all times.

9.3.3 Radiation Safety Testing

Radiation safety testing is required for any registrable source of ionising radiation to demonstrate compliance with conditions set out on the registration, and as stated in

Section 5 of Health (Radiation Safety) Regulations 1994. Testing is usually carried out when the source is first registered and again after **two** years of initial registration.

9.3.4 Exemptions

The Health Department of Victoria has the power to exempt and to apply conditions of exemption of any irradiating apparatus, sealed source apparatus or other radioactive substance that it considers is without significant radiation hazard. A list of exemptions may be found under Part 6 Health (Radiation Safety) Regulations 1994.

9.3.5 General Safety Precautions

These apply to the person/s responsible for any particular registered ionising radiation source or the licensee/s in possession of unsealed radioactive sources. This person must:

- Remain informed of hazards associated with the source.

- Provide to all employees and authorised visitors who may be exposed to ionising radiation from the source with safety instructions and equipment as necessary.

- Ensure that the radioactive substance does not leave its controlled area under circumstances that may permit exposures in excess of the current dose limits.

- Ensure the area where persons who are not radiation workers but who habitually occupy an area near the ionising radiation source, cannot be exposed to levels of ionising radiation above one tenth of the dose limits for radiation workers. (Note that this figure is now one twentieth with the most recent dose limits).

- Ensure that the radioactive source is not used, sold, stored, transported or disposed of in circumstances where a person may be exposed to ionising radiation in excess of the appropriate dose limit.

- Ensure that all radiation workers are over 18 years of age.

- Ensure that an ionising radiation source is protected from unauthorised access.

- Display warning notices as detailed under Section 44 & 45 of the Health (Radiation Safety) Regulations 1994.

- Notify the Health Department of Victoria (via the RPO) of a lost, damaged or relocated source of ionising radiation.

- Notify the RPO or Deputy RPO of any relocation of any sealed source of ionising radiation prior to relocation.

- Supply and maintain a correctly calibrated suitable radiation monitor as required under the conditions of the registration.

- Do not deal with a radioactive substance in such a way as to cause a radiation worker to be exposed to airborne radioactive material in an average annual concentration in excess of those in Table A3 of Australian Standard Safety in laboratories, Part 4: Ionising radiations (AS2243.4 (Int)) 1994.

- In the case of a person becoming contaminated with radioactive material, carry out or organise monitoring of the person at risk and that person's clothing as set out under Sections 47 & 48 of Health (Radiation Safety) Regulations 1994.

9.3.6 Control of Patient Dose

This is applicable to the use of ionising radiation apparatus or radioactive substances for medical diagnosis.

9.3.7 Radiation Safety Officer

A Radiation Safety Officer must be appointed in any workplace where ionising radiation sources are present. At Monash University these persons are the RPO and Assistant RPO. They are supported by departmental RSOs and deputy RSOs. The responsibilities of the RPO and RSO are set out in Appendices 1 and 2 of the Policy Statement.

9.3.8 Radiation Protection Limits

These are set out in Schedule 1, Health (Radiation Safety) Regulations 1994. The limits are set out in detail in Section 13 of this manual.

9.3.9 Personal Monitoring

This is detailed under Part 9 of Health (Radiation Safety) Regulations 1994. Personal monitoring is required for any person who is likely to be exposed to ionising radiation as a result of their work. The licensee or owner of a registered source of ionising radiation is responsible for instituting a personal monitoring program, at Monash University this is the RPO, department heads , RSOs and deputy RSOs.

The Department of Health and Community Services, Victoria has the power to specify the period that monitors must be worn. They can order that a radiation worker undergo biological monitoring and specify the intervals at which biological monitoring must be carried out. To date the Health Department has not made any special demands of the University.

The Health Department requires notification in writing within 24 hours of any exposure or suspected exposure exceeding 5 mSv in a single week. This notification is carried out by the RPO. Any suspected exposures should be immediately reported to the RSO or DRSO who should then take appropriate action.

Records of all personal monitoring, including annual exposures, are kept on the OHSE database and are available on request.

Personal monitoring is discussed in more detail in section 11 of this manual.

9.7 Medical Examinations

The Health Department may direct that a medical examination to be carried out on any person likely to be exposed to ionising radiation during impending, current or previous employment. The cost of the examination shall be borne by the licensee or registered owner of the ionising radiation source.

9.3.11 Transport of Radioactive Materials

The transport, storage, packaging and stowage of radioactive substances is covered by the Code of Practice for the Safe Transport of Radioactive Substances 1990 (known as "the Code of Transport" and revised since 1982) and the International Atomic Energy Agency Regulations for the Safe Transport of Radioactive Material 1985 (known as the "International Regulations" and revised since 1973). There are additional requirements in the Health (Radiation Safety) Regulations 1994 these **shall** be adhered to, before the requirements of the Code and the International regulations, where conflict arises.

Transport is covered in more detail in section 18 of this manual.

9.3.12 Disposal of Radioactive Waste

The licensee or registered owner of a source of ionising radiation **shall** not release wastes in a manner that will cause persons to receive more than the annual dose limits described in section 13 of this manual.

A licensee may discharge radioactive material through non-sewerage pipes or stacks in levels up to the limits set out in Schedule 5 Part 1, of the Health (Radiation Safety) Regulations 1994.

Radioactive material discharged into the sewerage system must be readily soluble and miscible with water, it is subject to conditions relating to the allowable limit of intake (ALI, see section 13 of this manual) for each radionuclide. Limits are set out in Section 73, Part 12 of the Health (Radiation Safety) Regulations 1994.

Solid radioactive waste is to be disposed of in accordance with specific conditions detailed on licences or registrations or with other methods approved by the Department of Health and Community Services. The RPO should be consulted where uncertainty exists.

Waste Disposal is discussed in more detail in section 16 of this manual.

9.3.13 Penalties

A maximum penalty of $10,000.00 is payable for an offence under the Health (Radiation Safety) Regulations 1994.

9.3.14 Enforcement

A specially authorised officer may at any time, enter a place where it is known or suspected that ionising radiation sources are kept and test, seize or render incapable of operation any ionising radiation source or demand to inspect all related documentation.

10. EXPOSURE TO IONISING RADIATION

10.1 Internal Exposure

10.1.1 Introduction

Internal exposure to ionising radiation is the irradiation of inner body tissues resulting from surface or airborne contamination that has entered the body.

The order of significance of each form of radiation as an internal hazard is as follows:

α increasing
β ⇑ internal
γ hazard
neutrons

It is the inadvertent release of unsealed sources (contamination) that poses the main threat as an internal radiation hazard. Such contamination may easily become incorporated in organs or tissues if it is not carefully controlled.

The extent and severity of an internal radiation hazard is related to the ionising capability of specific radiation types.

10.1.2 Routes of Entry into the Body

10.1.2.1 Inhalation

Unsealed radioactive material may exist as a gas, vapour or aerosol if it is in the airborne form. The fate of airborne radioactive material once inside the respiratory system depends on the size of its particles and their solubility in the lung fluid. Examples of airborne radioactive contaminants are iodine vapour or centrifuge aerosols.

The ICRP proffer the following as the likely fate of inhaled radioactive material:

- is exhaled in the next breath as it is too small to settle
- 50% is deposited in the upper respiratory tract (all areas of the respiratory tract except the lung) and is subsequently cleared to the throat and swallowed.
- deposits in the lung and is either cleared and swallowed or taken directly into the bloodstream

10.1.2.2 Ingestion

Unsealed radioactive material that exists as solid or liquid contamination on a work surface is the most common form of ingested radioactive material. This is usually a result of poor housekeeping, a lack of personal hygiene or allowing consumption of food in radioisotope areas. Ingested materials pass through the gastrointestinal tract with absorption and excretion being determined by solubility. Water soluble material will gain entry to the bloodstream and be readily passed to body organs. Insoluble material will pass through the gut and be excreted.

For example, iodine will go to the thyroid and plutonium or phosphorous will be deposited in the bone.

10.1.2.3 Absorption

Unsealed sources in a highly fat soluble, liquid form (e.g. organic solvents) are most commonly absorbed through the skin or mucous membranes. Usually this is the result of spills or splashes directly onto the skin or mucous membranes or material passing through an unsuitable glove. Solid or airborne liquid forms of unsealed, highly lipid soluble, radioactive material may be absorbed through the skin or mucous membranes. An example of this is isotope dissolved in ethanol.

10.1.3 The Kinetics of Isotope Clearance from the Body

When radioactive material is taken into the body, there is an initial rapid rise in the dose rate to the internal organs and tissues. This initial rapid rise is followed by exponential decay.

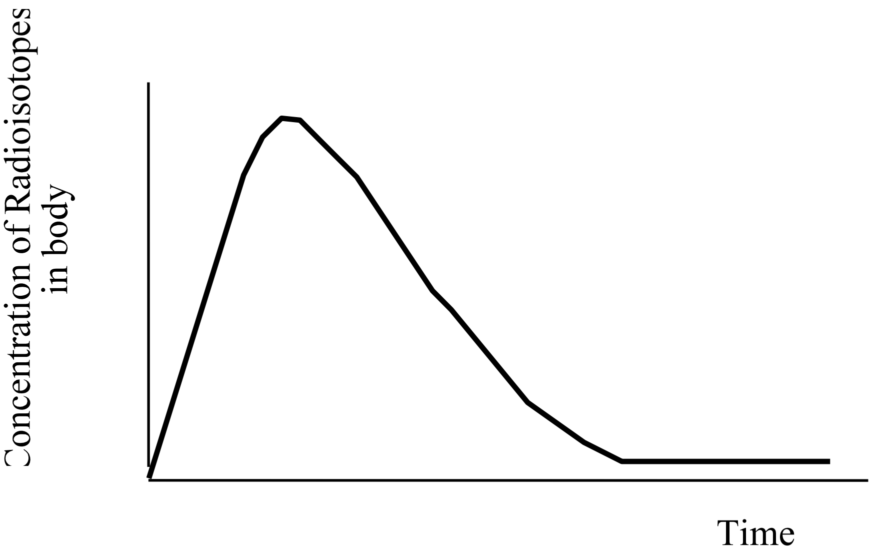


Figure 20: The kinetics of isotope clearance

The biological half-life (T_b) is a measure of the time taken for half of the radioactive material absorbed to be excreted from the body.

In reality however the effective half-life (T_{eff}) of radionuclides being excreted from the body is related to the radiological (T½) and biological half-lives by:

$$1/T_{eff} = 1/T_{1/2} + 1/T_b$$

10.2 External Exposure

External exposure to ionising radiation arises from sources outside the body. Sealed and unsealed sources and irradiating apparatus may all become external radiation hazards if handled incorrectly.

The order of significance of each form of radiation as an external hazard is as follows:

α		increasing
β	⇓	external
γ		hazard
neutrons		

The extent of severity of an external radiation hazard is related to increasing penetrating power of the radiation. In practice, alpha radiation is not regarded as an external hazard, due to its low penetrating power.

10.3 The Summation of Internal and External Exposure

In assessing overall exposure to ionising radiation, the total internal and external doses must be summed as follows:

$$\text{Total Exposure} = \frac{H_w}{H_{wb,L}} + \sum_i \frac{I_i}{I_{i,L}}$$

Where: H_{wb} = annual equivalent dose from external exposure
$H_{wb,L}$ = annual equivalent dose limit
I_i = annual intake of radionuclide i
$I_{i,L}$ = annual ALI for radionuclide i

Where the sum of this equation is ≤ 1 no over exposure has occurred.
Where the sum is > 1 over exposure has occurred.

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11. MONITORING FOR IONISING RADIATION

11.1 Introduction

The purpose of workplace radiation monitoring is twofold:

- Personal monitoring (monitor worn on the person) for the purposes of assessing the equivalent dose to the whole body or extremities.

- Area monitoring (monitor placed in a specific location/s) for the purposes finding contamination or assessing dose rates from specific sources of ionising radiation.

Records must be kept for all measurements pertaining to ionising radiation in accordance with section 21 of the Policy Statement.
Monash University policy on monitoring for ionising radiation is set out in sections 26 and 32 of the Policy Statement. Section 9 of AS 2243.4 contains specific directives for monitoring ionising radiation.

11.2 Types of monitoring

11.2.1 Dosimetry

11.2.1.1 External dosimetry

External dosimetry may be performed for the whole body or for parts of the body.

- ***Whole body dose***

The whole body dose can be assessed by a single personal dosimeter only if the wearer is in a uniform radiation field. The whole body external exposure is measured using a thermoluminescent dosimeter which is worn by the individual on the waist, as the gonads are the most radiosensitive organ. Users of neutron moisture meters should wear personal, neutron radiation monitors.
A personal dosimeter should be supplemented with direct reading dosimeters (e.g. Quartz Fibre dosimeter or a digital alarm dosimeter), when there is the potential for high doses over a short period (usually minutes or hours).
The normal period for wearing a whole body TLD is 8-12 weeks, except for pregnant women (4 weeks). All persons working with ionising radiation (i.e. radiation workers), at the University shall be provided with and will be required to wear personal monitoring devices.

Each personal dosimeter should be numbered, used by one person only and returned promptly at the end of the issue period. In the event of a suspected high dose, arrangements should be made with the relevant personal dosimetry service for the particular dosimeter(s) to be processed and assessed as quickly as possible. This is the responsibility of the RSO or deputy RSO.

- **Dose to Parts of the Body**

Work in close proximity to radiation sources of small dimensions or with devices producing narrow beams of radiation, may expose persons to non-uniform radiation fields. In this case a part of the body, particularly the fingers, may be exposed to high doses. "Finger TLD" dosimeters should be worn by staff working with phosphorus-32 unsealed source or x-ray diffraction x-ray fluorescence apparatus, particularly when engaged in sample manipulation or beam alignment.

Additional personal dosimeters (for measuring dose to extremities) are sometimes worn on the wrist, forehead or other parts of the body.

Extremity monitoring should be on an as needed basis, at the discretion of the RSO or deputy RSO. It is only required for high energy beta emitters. Beta radiations from tritium and carbon-14 are regarded as too low energy to be detectable with a finger TLD.

Where additional dosimeters are needed to estimate doses to extremities of the body a special issue of dosimeters should be arranged through Australian Radiation Laboratory by the RSO or deputy RSO.

11.2.1.2 Internal

- ***Personal contamination***

Immediately after any procedures that use sources of sealed or unsealed ionising radiation, the hands and laboratory coat should be examined with a count rate meter. Such contamination is the most frequent source of internal exposure via ingestion or absorption.

- ***Thyroid monitoring***

Monash University requires that all persons who use radioactive iodine undergo regular thyroid monitoring. Radioactive iodine concentrates in the thyroid and persons routinely involved in handling radioiodine should have their thyroid gland monitored at six monthly intervals. If radioactive iodine is being used regularly, monitoring must be performed monthly, and immediately following any major task using the isotope. In the case of persons infrequently using radioiodine, thyroid monitoring should be carried out after each radioiodine manipulation.

The thyroid monitor utilises a crystal of sodium iodide as the detector. This is placed near to the throat and the result obtained after 2 minutes of counting (in Becquerel) is compared with the ALI (see section 13).

- ***Whole body monitoring***

  Gamma and X emitting radionuclides and beta emitting radionuclides that have sufficient energy to produce bremsstrahlung when distributed in the lungs or throughout the whole body, can be monitored with whole body counters. Whole body counters are ineffective for beta emitters except for those producing bremsstrahlung. The difficulty lies in monitoring radiation that is distributed in a non-uniform manner.

  A large shielded room (to reduce background) with a flat bed or tilted chair (at 45 degrees) and a large sodium iodide detector are required. The detector is placed over the abdomen. Sensitivity depends on the individual radionuclide. Results are expressed in ALIs (see section 13).

  Monash University has no facilities for whole body monitoring of internal exposure to ionising radiation. If deemed necessary, whole body monitoring can be arranged through the RPO or Assistant RPO.

- ***Bioassay***

  Urine, faeces, blood and sweat may be counted routinely or after (within several hours) of a suspected or known exposure for a measure of internal radiation exposure to certain radionuclides. Urine monitoring for tritium and carbon-14 beta emitters is the only bioassay monitoring commonly performed at Monash University. Measurements taken long after exposure has occurred may not be representative of a peak exposure e.g. Tritium may be measured in urine by liquid scintillation counting, (sensitivity $\cong$370 Bq L^{-1}).

  The urine of persons working with unsealed sources of ionising radiation should be performed regularly, provided the technique is thought to be reliable. A list of the results should be retained to enable comparisons with the ALI for inhalation (see section 13). Thus, any count that has increased significantly since the last measurement can then be investigated.

11.2.2 Area

11.2.2.1 Dose rates from surfaces

Radiation dose levels can be monitored with a dose rate meter. This is a method commonly used for identifying any “hot spots”.

Extensive monitoring should be carried out during and immediately after the installation and testing of new apparatus or after changes in experimental protocols and techniques. Once the pattern of radiation from X ray producing apparatus has been established, subsequent surveys may be less detailed.

Particular problems arise with narrow beam X ray apparatus (e.g. X ray diffractometers), because the primary beam or sheets of scattered radiation are generally very small in cross-section. A small volume, sensitive detector should be used.

Photographic methods may also be useful to detect the extent of the beam. Monitoring of such apparatus should be performed with great care whenever experimental conditions have been changed in any way.

Electron microscopy and diffraction (as distinct from X-ray diffraction) apparatus presents fewer problems. A thorough initial survey when the equipment is installed is usually sufficient. However, additional shielding can be added if necessary, in places where the dose rate is high.

Surveys should be frequent where sealed or unsealed radioactive materials are used, because the materials can be moved causing changes in the radiation pattern.

11.2.2.2 Contamination on surfaces

- ***Using a count rate meter***

  The instrument most commonly used to measure radioactive contamination on surfaces is a count-rate meter. There is no satisfactory simple instrument for the direct monitoring of tritium surface contamination.

  Because both alpha particles and low-energy beta particles have very limited ranges in air, the detector must be held very close to, but not actually touching, the surface under investigation.

  If inferences are to be made about dose using a count rate meter, then the meter must be calibrated in such a way that count rate can be related quantitatively to dose rate.

- ***Wipe or smear testing***

  Wipe or smear testing should be used when direct monitoring is inappropriate. For example:-

  - ◊ Monitoring for low energy beta emitting surface contamination. e.g. Tritium, carbon-14 or sulphur-35.
  - ◊ An interfering high radiation background is present.
  - ◊ The surface to be monitored is inaccessible to the probe of a contamination monitor.
  - ◊ Direct monitoring underestimates the degree of contamination because of self absorption effects.
  - ◊ The degree of removable contamination is to be estimated.

  Performing a wipe test: Use a filter paper or tissue to wipe an area for contamination. The wipe should be moistened with deionised water or an appropriate solvent. When a surface is wiped, only a percentage of the removable contamination will be collected. Factors affecting the collection or wipe efficiency include:

The pressure exerted when taking the smear.
The measurement of the area smeared.
The condition of surface tested.
The solvent used.

An area of at least 0.5-1m^2 should be wiped. The smear samples must then be counted in an area of known low background. Counting may be performed using a scintillation counting instrument or a hand held meter. The choice of instrument will be dependant upon the type of isotope present as contamination.

The extent of contamination can be determined in terms of numbers of "derived working limits" (see section 13 for further explanation). To compare wipe test results with the DWL (this is expressed as an activity per area of surface) the counting instrument must be calibrated and the detection limit must be checked.

Calibration - Counting Instrument Efficiency (E_c): This can be determined by placing a source of known activity at the same distance from the detector as the measurement will be done. The formula below can be used to calculate the counting instrument's efficiency. Do this calibration in an area of low background.

$$E_c = \frac{\text{Counts measured}}{\text{Activity expected (Bq)}} \times 100\%$$

(This formula relates the count rate to activity)

If you do not have a suitable source for calibration then as a worst case assumption use $E_c = 10\%$.

Detection Limit: The detection limit of the instrument can be determined once the counting instrument's efficiency has been determined. It is important that the detection limit of the counting instrument be one DWL or lower. The equation below can be used to calculate the detection limit of the instrument in DWL's.

$$\text{Detection Limit} = \text{DWL} \times \frac{E_c}{100} \times A_s$$

Where A_s = surface area of the detector (m^2)
- usually about 0.1 m^2 is used.
E_c = Counting Instrument Efficiency (%)
DWL = appropriate DWL from AS2243.4
Detection Limit will have the units counts per second per DWL.

The detection limit per DWL must be above background, preferably twice background to ensure that contamination above the DWL can be detected.

Comparing Measurements to the DWL: The measured count rates can be converted into an activity per area wiped, i.e. a Contamination Level, using the equation below. This contamination level may then be directly compared with the appropriate DWL.

$$\textit{Contamination level } (Bqm^{-2}) = C_c \times 100/E_c \times 1/A_s \times 100/E_E$$

A_s = ***Area smeared (m^2)***
C_c = ***Count rate corrected for background.***
E_E = ***% Contamination picked up by paper. (Assume 10% unless your know otherwise).***

11.2.2.3 Monitoring airborne contamination

Airborne contamination may easily occur in laboratory situations. If operations involving radioactive materials may produce airborne contamination in the breathing zone, some form of monitoring should be instituted. Air concentration of radioactive contaminants is measured in "derived air concentrations" (DAC). See section 13 for further details. Air monitoring should be instituted with the assistance of the RPO. Further discussion is beyond the scope of this manual.

11.3 Calibration and Performance Checking

All monitoring instruments shall be calibrated when first taken into use and at annual intervals thereafter and following major repairs or service. Records of the date and results of all calibrations shall be kept for two years after disposal of the instrument. Calibration must be carried out at a laboratory equipped with calibration facilities. e.g. The Australian Radiation Laboratories, Australian Nuclear Science and Technology Organisation (ANSTO) or the Health Department of Victoria.

The RPO will advise departments of the due dates for calibrations. Departments will be responsible for ensuring instruments are calibrated, paying for the calibration and advising the RPO of the outcome.

Between annual calibrations, the RSO or deputy RSO should carry out constancy checks. Where possible these should be made with the same type of radiation for which the instrument is designed. The procedure for a constancy check is to place a source of known count rate (this is not the same as activity) or dose rate (whichever is appropriate to the instrument) for a specified distance, at that distance from the detector. The subsequent readout on the instrument should be recorded for comparison with past and future constancy checks. Any reading that deviates more than 10% from previous ones or any trend in changing response necessitates a complete service of the instrument. This should be done through the manufacturer, if possible, to avoid negating any warranties on the equipment.

No detector can be calibrated or performance checked using one type of radiation and reliably used to quantify other types of radiation. Be aware that some instruments have multiple detectors for working over large ranges. Calibration and performance checking must consider all of these as independent detectors.

11.4 Types of Instruments for Measuring Ionising Radiation

11.4.1 Count rate meters

These give a readout in counts per unit time in proportion to the number of ionisation events that occur within their detector. Note that count rate is not the same as activity. They are usually instantaneous readout instruments.

Common types of detectors used as count rate meters include; Geiger-Muller, ion chamber, proportional and scintillation detectors.

11.4.2 Dose rate meters

These give a readout in dose units (Sievert or Gray) per unit time. They work on the same basic mechanisms as count rate meters except that they sometimes include provision for distinguishing between different types of radiation. e.g. A sliding plastic plate across the detector to distinguish between alpha and beta radiation. They are instantaneous readout instruments.

Common types of detectors used as dose rate meters include; Geiger-Muller, ion chamber, proportional and scintillation detectors.

11.4.3 Dosimeters

A readout may be obtained some time after measurement or it may be a direct read out instrument. The dosimeter is worn by the person to whom it is assigned for the purposes of dose measurement over a reasonable period of time. A dosimeter should be worn on the part of the body exposed to the highest dose rate of ionising radiation. Dosimeters are a whole body or extremity monitor.

Types of detectors used as dosimeters; ion chamber QFD (quartz fibre dosimeter), Geiger-Muller, DAD (digital audio dosimeter), film badges and TLD (thermoluminescent detectors).

11.5 Choice of a Monitoring Instrument

No single ionising radiation detector is universally applicable to all types and quantities of ionising radiation. The following factors should be taken into account when choosing a monitor.

11.5.1 Type and energy of radiation

Geiger-Muller or ionisation chamber detectors are generally the best for area monitoring of alpha and beta radiation.

Very soft beta emitters (≤0.25 MeV) such as tritium, carbon-14, sulphur-35 and calcium-45 may require initial concentrating before detection with thin window geiger probes.

A proportional counter is commonly chosen for neutrons and sometimes alpha radiation.

Scintillation detectors are commonly chosen for all gamma emitters.

The TLD or QFD will measure all types of radiation except alpha radiation and very low energy beta radiation, e.g. Tritium, carbon-14.

11.5.2 Units

The meter should read in SI rather than imperial units (American system), for easy comparison with current standards.

11.5.3 Sensitivity

The meter should have sufficient sensitivity for the applications required. High sensitivity may be required for measuring low level contamination. In this case, a large surface area detector will be needed. However, if such an instrument is used to measure high levels of contamination, partial saturation of the detector may result leading to a low response. The response time (dead time plus recovery time) of the instrument may be too slow for measurement of pulsed radiation fields (e.g. fractionated X rays) unless the instrument has been specifically chosen for the purpose.

11.5.4 Interferences

Radio frequency fields (non-ionising radiation) will affect the meter readout unless the detector is adequately shielded.

11.6 Measurement Characteristics of Specific Instruments

11.6.1 Ion chamber detectors

Principle of Operation: Radiation causes direct ionisation of the gas (usually air) in the chamber. Ions are attracted to opposite electrodes and the resulting current is measured.

Usage: Ionisation chamber detectors can be used for beta, X, or gamma and sometimes also alpha radiation as well (this may vary between brands).

These make excellent field instruments, but they can be heavy as a portable instrument. Other advantages are:

- High pressure, large volume chambers give increased sensitivity.

- Energy response is fairly linear and mostly dependent on the chamber wall thickness. Such an instrument has a wider linear range than a Geiger-Muller tube.

11.6.2 Proportional detectors

Principle of Operation: Their mechanism is similar to an ion chamber except that a higher potential is selected so that the output signals are proportional to the energy of the radiation causing the ionisation events in the chamber. This results in selective measurement of different radiations. A series of single pulses result.

Usage: Proportional detectors are common for alpha and neutron measurement.

These instruments are characterised by their sensitivity to low levels of radiation.

11.6.3 Geiger-Muller detectors

Principle of Operation: Geiger-Muller detectors operate at higher voltages than proportional counters causing an avalanche of ionisation and a large pulse of current for every ionisation event in the chamber. This makes them very sensitive. One must take care not to set operating voltage too high or ionisation gas in the chamber will be consumed.

Usage: They are excellent for many beta, gamma and X radiations. Digital audio dosimeters are generally small Geiger-Muller detectors and they provide a readout of dose and have alarm capabilities.

Some of the advantages of these detectors are:

- Geiger-Muller detectors are small, rugged and have a large linear region and a rapid response.
- They have long dead-times (100-200 msecs) where no pulse can be registered, and may register a response to intense light or high temperatures.

A disadvantage with these units is that can be sensitive to high radiation fluxes, exhibiting fold back (saturation of the tube and zero reading) acutely, in very low or high radiation fields. If the electronics are well designed these problems can be minimised.

11.6.4 Scintillation detectors

Principle of Operation: The mechanism of a scintillation detector is based on fluorescence radiation when a material called a "scintillant" contacts ionising radiation. The scintillant emits light in proportion to the energy of the incident radiation. A photomultiplier tube can be used to detect this light.

Usage: The choice of the scintillant determines the type of radiation which will be detected. Zinc sulphide is a common used scintillant for alpha detection and sodium iodide is a commonly used scintillant for gamma detection.

Scintillation detectors are very sensitive and are generally used for low levels of gamma or X radiation.

A disadvantage with these units is that they can be affected by magnetic fields. Another problem is that all light must be excluded from the detector due to the principle used for detection.

11.6.5 Thermoluminescent detectors (TLD)

Principle of Operation: When ionising radiation interacts with thermoluminescent material it causes a change in the excitation state of the material. When the material is heated, it releases the energy as light.

Usage: The thermoluminescent material commonly used is lithium fluoride, which is cheap and has a nearly flat energy response curve over the entire range of interest for personnel dosimetry. TLDs are used for all types of radiation measurement including neutrons. The common TLD will not measure alpha or low energy beta. e.g. Tritium, this is mostly due to the fact that these types of emission will not have the range to reach the TLD.

There is no permanent, physical record of exposure and the badge is re-useable.

11.6.6 Film badges

Principle of Operation: Ionising radiations cause darkening of the chemicals used on film. The amount of darkening is used as a measure of the exposure for the operation of these badges.

Usage: Previously used for personal dosimetry for most types of radiation. All radiation types are now measured with a TLD

Their main disadvantage is that they are less sensitive than a TLD.

11.6.7 Quartz fibre electroscope (QFD)

Principle of Operation: Quartz fibre electroscopes are miniature ionisation chambers where the quartz fibre is electrostatically repelled when the chamber is initially charged. Fibre must be zeroed in order to get accurate dose reading. Ionising radiation causes a change in the ionisation state and thus the quartz fibre changes position relative to a scale on the glass of the chamber.

Usage: They may be obtained to measure for X, gamma, beta or neutrons. They are used for short term assessment of total dose and are somewhat susceptible to knocks and moisture.

11.6.8 Neutron Detectors

Chemical reaction and activation detectors (specifically for neutrons) are also used for radiation measurement. The type of neutron will determine the principle of detection used.

11.6.8.1 Fast neutrons

Principle of Operation: The neutrons induce radioactivity in other materials, which can then be measured. Chamber requires some shielding.

11.6.8.2 Slow neutrons

Principle of Operation: Detectable in the same way as fast neutrons but the chamber has no shielding.

$$n + {}^{10}B \rightarrow {}^{7}Li + {}^{4}He\ (\alpha)$$

The disadvantages associated with this type of detector are that it also responds to γ and it is very heavy.

11.6.9 Other

11.6.9.1 Induced radiation detectors

Principle of Operation: Induced radiation detectors are systems in which radiation interacts with materials to form radionuclides whose radiation can be measured eg. indium foil for detecting neutron radiation. Proper selection of the foil permits evaluation of the neutron energy spectrum. Not a common detector.

11.6.9.2 Chemical reaction detectors

Principle of Operation: Radiation causes a change in a chemical system, e.g. chloroform with water and a dye indicator to measure the acid formed due to irradiation. These detectors have low sensitivity, and are not extensively used.

12. THE PHILOSOPHY OF IONISING RADIATION PROTECTION

12.1 Introduction

The primary aim of ionising radiation protection is provide an appropriate standard of protection to people, without unduly limiting the beneficial practices of ionising radiation usage that may give rise to radiation exposure. The ICRP stipulate that the standard of protection should be based on an intention to prevent the occurrence of deterministic effects by keeping doses below relevant thresholds and to ensure that all reasonable steps are taken to reduce the induction of stochastic effects. To this end the following three tenets apply to all practices with ionising radiation:

a) The justification of practice

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

b) The optimisation of protection

The magnitude of individual doses, the number of people exposed and the likelihood of incurring exposure that was not anticipated, should be kept As Low As Reasonably Achievable (the ALARA principle), economic and social factors taken into account.

c) Individual dose and risk limits

The exposure of individuals should be subject to dose limits and there should be some control of risk in the case of potential exposures.

12.2 Types of Exposure to Ionising Radiation

12.2.1 Occupational exposure

"Occupational exposure" encompasses all exposures to radiation incurred at work as a result of situations that can reasonably be regarded as the responsibility of operating management. Natural radiation exposure due to potassium-40, cosmic rays at ground level and radionuclides in the earth's crust are all excluded from this definition as they are outside management control. Only radon in workplaces and work with material containing radionuclides can reasonably be regarded as the responsibility of operating management, and even then, only in the following cases:

- Operations in the workplace where the regulatory agency has declared that radon needs attention and has identified the relevant workplaces;
- Operations where the storage of materials is not usually regarded as radioactive, but which contain significant traces of natural radionuclides and which have been identified by the regulatory agency;
- Operation of jet aircraft; and
- Space flight.

12.2.1.1 Control strategies used for occupational exposure

Optimisation of protection

The ICRP recommend that optimisation of protection should be carried out by the regulation of practices. This is the reason behind many of the guidelines, Australian Standards and codes of practice that have been incorporated as an adjunct to radiation safety law in Victoria. The optimisation of protection only takes into account actual exposures. Potential exposures are dealt with in a section 12.2.4.

Setting of dose limits

Dose limits are recommended to cover a wide range of occupational situations and to provide an upper limit to any constraints applied under optimisation of protection. In setting dose limits for occupational exposure the ICRP have defined three subjective terms in relation to the tolerability of the wider community towards the consequences or risk of an exposure

- "Unacceptable".

- "Tolerable" (unwelcome but reasonably tolerated).

- "Acceptable" (no further improvement required. i.e. the control of the process has been optimised).

The ICRP have aimed at setting the dose limits on the boundary between unacceptable and tolerable in relation to a normal operation of any practice of which the use of ionising radiation was a matter of choice. Exposures above the boundary between unacceptable and tolerable may have to be accepted in abnormal situations such as accidents.

In setting dose limits the ICRP has taken into account the following contributing factors to health detriment:

- Probability of death.
- Probability of severe hereditary conditions.
- Length of life lost due to an attributable death.
- Incidence of non-fatal conditions.

The ICRP recommends a dose limit based on annual, average dose over a working life time of 47 years. After examining mortality and morbidity data in their 1990 recommendations (ICRP 60), the ICRP have come to the conclusion that the total effective dose to a worker over the period of his or her entire working life should not exceed approximately 1 Sv, received uniformly, year by year. In theory the ICRP is in favour of a life time dose limit for occupational exposure but recognises the practical difficulties in controlling this while workers change jobs. Consequently a 5 year exposure limit is given in addition to the annual dose limit.

The ICRP found that the skin and the lens of the eye may not be protected adequately by a limit on whole body dose, particularly in the case of external exposure. Consequently these tissues have been given different dose limits of their own.

The ICRP has established annual limits of intake (ALI's) for a wide range of nuclides. An ALI is the quantity of a radionuclide acquired as an internal contaminant which would give an annual dose commitment of 20 mSV, considered over 50 years. Due weighting is given to the effects of radiation to the various bodily organs. This dose is related to "reference man" and does not take into consideration various physiological differences.

Dose limits for occupational exposure are not intended to make any allowance for medical or public exposure incurred by workers.

Protection of women

The basis for setting dose limits for women is the same as that for men except when a woman is pregnant. In this case, the unborn child must be protected at a level that is as restrictive as for a member of the public. In turn, this should restrict the work activities of women during pregnancy to employment of a type that does not carry a significant probability of high accidental doses or intakes.

Section 30 of the Policy Statement contains guidelines on Monash University's policy in relation to pregnant women and exposure to ionising radiation.

12.2.1.2 Medical Exposure

The following exposures are considered to constitute medical exposures:

- Exposure incurred by individuals as part of their own consented medical diagnosis or treatment.
- Non-occupational exposures incurred willingly and knowingly by individuals who are supporting or comforting patients undergoing irradiation for medical purposes.
- Exposures incurred by individual volunteers as part of a programme of biomedical research.

12.2.1.3 Control strategies used for medical exposure

Justification of practice

Consideration must be given to the possibility of potential, occupational and public exposures in justifying medical procedures involving the use of ionising radiation. Justification in relation to the patient is considered in terms of the total amount of exposure that is foreseeable and prior to each individual use of ionising radiation for diagnosis or treatment.

Optimisation of protection

Constraints on investigation levels are recommended for medical procedures involving the use of ionising radiation on patients or its use on volunteers in scientific or clinical studies. Several codes of practice provide information on this (see Appendix B).

Setting of dose limits

The ICRP does not recommend any dose limits in relation to medical exposure because doses must be given commensurate with medical purposes. Any attempt by regulatory authorities to set dose limits for medical purposes may result in added detriment to a patient.

Protection for women

Diagnostic and therapeutic procedures involving the use of ionising radiation should be avoided during pregnancy unless there are strong clinical indications for their necessity.

12.2.2 Public Exposure

Public exposure includes all exposure to natural and artificial radiation sources that is not classifiable as either occupational or medical exposure.

12.2.2.1 Control strategies used for public exposure

Optimisation of practice

The main aim of optimisation of practice in the control of public exposure should be to develop practical restrictions on the sources of exposure. See Appendix B for some of the codes of practice that provide guidelines in this matter.

Setting of dose limits

Dose limits for public exposure are not intended to cater for potential exposures. The ICRP has chosen a dose limit for public exposure which lies between unacceptable and tolerable as defined by the ICRP and is based on the variations in existing levels of dose obtained from natural sources.

The dose limit is intended to be applied to exposures that are the result of practices whose use is a matter of choice. There is an annual dose limit and a dose limit that is to be applied over a 5 year period. Radon in dwellings and in the open air and radioactive materials whether natural or artificial, already in the environment are outside the scope of limits for public exposure.

The ICRP has adopted an arbitrary reduction factor of 10 in deciding on dose limits for the eye and skin tissue because the general population show a wider range of sensitivity than the working population.

Dose limits for public exposure are not intended to cover exposures that are incurred by a person in the course of their occupation.

12.2.3 Potential Exposures

The concept of health detriment does not include probabilities for potential exposures due to the inherent difficulty in quantifying them. Nevertheless, every effort must be made to control potential exposures. Potential exposures may be occupational, medical or public.

12.2.3.1 Control strategies for potential exposure

Justification of practice

The estimate of detriment from potential exposures will be very difficult to quantify prior to considerable experience being attained with the ionising radiation practice concerned. A re-justification of practice may be necessary once a better estimate of the contribution to detriment of potential exposure has been made.

Optimisation of practice

One must be careful that measures put into place to reduce the risk of potential exposures do not increase the incidence of occupational exposures. The reduction in public exposure by reducing incineration and increasing storage of waste may result in an increase in potential occupational and public exposures.

Setting of risk limits

In theory a risk limit should be defined in relation to the attributable probability of death, however this is very difficult due to the multiple scenarios from which an exposure may arise. As a consequence, the ICRP does not yet recommend risk limits for potential exposures.

12.2.4 Occupational Exposure in Accidents and Emergencies

The ICRP makes special provision for higher dose limits in the case of accidents or emergencies. However, there are special conditions that apply to such situations and any decision to apply such limits is the exclusive right of the Department of Health and Community Services, Victoria in conjunction with the RPO.

13. LIMITS OF ACCEPTABLE EXPOSURE

12.1 External exposure

12.1.1 ICRP Dose Limits

The ICRP have stipulated the following dose limits in ICRP 61. The limits are formally written into legislation in Victoria and have been adopted by the Department of Health and Community Services, Victoria and the RPO.

Dose limit[1]		
Application	**Occupational**	**Public**
Effective dose	20 mSv[1] per year averaged over discrete periods of 5 years[2]	1 mSv in a year[3]
Annual equivalent dose in:		
the lens of the eye	150 mSv	15 mSv
the skin[4]	500 mSv	
the hands and feet	500 mSv	50 mSv[5]

Notes:

1. The 20 mSv annual limit applies to the sum of:
The relevant doses from external exposure in the specified period.
The 50 year committed dose (to age 70 years for children) from intakes (internal exposure) in the same period.

2. The effective dose may also be defined as 100 mSv averaged over 5 years and must not exceed 50 mSv in any single year.

3. The average in a single year may fluctuate, provided that it does not exceed 1 mSv when averaged over 5 years.

4. The limitation on effective dose provides sufficient protection against stochastic effects and applies to the skin of the face. The 500 mSv dose is averaged over any 1 cm^2 area of skin regardless of the area exposed. This additional limit is needed to protect against deterministic effects from localised exposures.

5. The ICRP do not define this limit for members of the public.

Table 17: Dose Limits

A supplementary limit applies to protect the unborn child because a dose to the uterus can be taken to be the dose to the whole body of the embryo or foetus. This is an effective dose limit of 2 mSv for the abdominal area for the remainder of the pregnancy.

An individual equivalent dose limit for the thyroid gland is no longer recommended by the ICRP, although such a limit is stated in the NH&MRC publication on "Recommended Radiation Protection Standards for Individuals Exposed to Ionising Radiation" (currently enacted under legislation in Victoria).

The "non-stochastic" limit of 500 mSv annually has also been used for the thyroid, but even this is not recommended in ICRP 60. All the dose limits given in ICRP 60 are designed to prevent deterministic effects. The only tissues that have equivalent dose limits of their own are the lens of the eye and the skin. The lens of the eye makes a negligible contribution to effective dose and the skin may be subject to localised exposures.

13.1.2 Monash University Action Limits

The RPO has imposed action limits on external radiation exposures to university personnel. The action limits are set at 10% of each ICRP dose limit.

Any exposure above the action limit will be followed up by the RPO in association with the RSO or deputy RSO and the individual concerned.

13.2 Internal Exposure

13.2.1 Annual Limits of Intake (ALI)

The ALI is given for individual radionuclides separately for ingestion and inhalation. 1 ALI is the limit of radionuclide which, when absorbed by inhalation or ingestion would irradiate the worker to the committed effective dose limit of 20 mSv annually. Current ALIs for common radionuclides are given in ICRP 61, and Table A3 in Australian Standard 2243.4 (1994)int. The ALI values may be averaged over 5 hears to provide some flexibility. They are designed to prevent deterministic effects.

For members of the public the ALI is 1 mSv, (AS2243.4). However, the NH&MRC has not yet endorsed this value.

ICRP 60 stipulates that intakes of radionuclides for pregnant women working with ionising radiation should be reduced to 1/20 of the ALI as soon as the pregnancy has been declared. This limit will stay in force throughout the remainder of the pregnancy and thus protect the unborn child.

13.2.2 Limits for Area Contamination Internal and External Exposure

Derived air concentration (DAC)

One DAC is the air concentration of the radionuclide that would result in a worker receiving one ALI through a single years exposure. A DAC is calculated as follows:

$$\text{DAC} = \frac{\text{ALI}}{2.4 \times 10^{-3}} \quad \text{Bqm}^{-3}$$

The DAC is derived from the ALI as defined in ICRP 61 as well as AS2243.4.

The DAC for members of the public is taken as 1/100 of the occupational ALI. This is done on the basis that a member of the public in 24 hours, breathes 2.4 times the volume of air that a worker does in 8 hours. In addition the member of the public inhales the radioactive material for 365 days a year. Whereas the worker only inhales it for 250 days.

Derived working limit (DWL.)

ONE DWL represents the maximum allowable limit of surface contamination if the effective dose limit is not to be exceeded on an annual basis for either occupational or public exposure.

Derived limits are designed to control surface contamination such that:

- The amount of contamination released does not cause the DAC to be exceeded.
- The amount ingested does not cause the ALI to be exceeded.
- If on the skin, the skin dose does not exceed the equivalent dose for the skin.

The ICRP and the Health Department of Victoria do not stipulate derived limits for various radionuclides. DWL’s are set out in Appendix A of Australian Standard AS2243.4. The DWL is dependant upon the radiotoxicity of the radioisotope as shown in table 18.

Class	**Radiotoxicity**	**DWL (Bq.cm^{-2})**
I	very high	0.01
II	high	0.10
III	moderate	1.00
IV	low	10.0

Table 18. Derived Working Limits for Classes of radionuclides.

14. CONTROL MEASURES FOR IONISING RADIATION

14.1 Hierarchy of controls

Once an ionising radiation hazard with unacceptable risk has been identified, suitable control measures must be established. The following approach, from most to least desirable, should be taken in deciding on control measures for a specific ionising radiation source.

14.1.1Removal

Removal involves seeking an alternative to the use of ionising radiation for the purpose. This is the most desirable option.

14.1.2 Substitution

Substitution entails substituting a less hazardous radionuclide. AS2243.4 (1994) Appendix B, Table B1, should be consulted for the relative toxicities of radionuclides.

14.1.3 Isolation

It may be possible to completely or partially isolate the source of ionising radiation such that it presents a negligible risk to persons nearby.

Remote control operations or operations at a distance are the best examples of isolation.

14.1.4 Engineering Controls

If the source cannot be removed, substituted or isolated, it may be possible to control the emanating radiation. Shielding is the best method.

14.1.5 Personal Protective Equipment

Shielding of the workers may be needed to prevent personal contamination and external exposure.
Examples of personal protective equipment include:

- Lead aprons to shield external exposure for X and γ sources.
- Rubber gloves and overshoes to prevent personal contamination.
- Goggles or faceshields to protect against splashes.

14.1.6 Administrative Controls

This is the least desirable option and if chosen, should be used in conjunction with other control measures.

Administrative controls include the following:

- Designated radiation areas (DRAs).
- Warning signs.
- Procedures, general rules and policies.

14.2 Control Measures Specifically for External Radiation Hazards

14.2.1 Time

The total dose is directly proportional to the time of exposure.

dose = dose rate x time

Consequently time spent in an area where significant exposure may occur must be kept to a minimum. If the dose rate is known at a particular geographical location in relation to a source of ionising radiation then it is possible to calculate the maximum permissible time that may be spent in this area using a suitable portion of the equivalent dose limit.

14.2.2 Distance

14.2.2.1 Gamma & X Ray

Dose rate from gamma source is inversely proportional to distance and is given by either one of the following relationships:

$$DR = \frac{AE}{6r^2} \qquad (1)$$

Where DR = Dose rate in μSvh^{-1}
A = Activity of source in MBq

E = Gamma energy per disintegration in MeV
r = Distance from source in meters

This can be further reduced to the following equation:

$$DR = \Gamma A/d^2 \qquad (2)$$

Where
DR = Dose Rate in μSvh^{-1}
Γ = specific gamma ray constant (given in AS 2243.4 Table A3). It is the dose rate in mSvh^{-1} from a 1 GBq source at 1m
A = Activity in GBq
d = Distance from source in metres

The inverse square law that relates dose to distance from a point source is also used in the following form:

$$DR_1\, r_1^2 = DR_2\, r_2^2 \qquad (3)$$

Where
DR_1 = dose rate at distance $\mathbf{r_1}$ from source
DR_2^1 = dose rate at distance $\mathbf{r_2}$ from source

Examples of calculations using the inverse square law are contained in Appendix C.

14.2.2.2 Beta

Beta rapidly loses energy in its passage through air, thus there are no straightforward equations to relate the behaviour of the dose rate from beta radiation as a function of distance.

14.2.3 Shielding

14.2.3.1 The purpose of shielding

The purpose of shielding is to ensure that the dose received by persons is as low as reasonably achievable and is well below the dose limits.

Sealed and unsealed sources and apparatuses which emit penetrating ionising radiation (e.g. X, gamma, beta or neutron radiation) may need to be shielded. Shielding required depends on the type and energy of the radiation emitted and its intensity.

Calculations for shielding applications are included in Appendix C of this manual.

14.2.3.2 Shielding for various forms of radiation

Alpha radiation

Alpha radiation does not require shielding due to its extremely low penetrating capability. It will be stopped by a sheet of paper or the outer layer of human skin.

Beta radiation

For shielding beta radiation, low atomic number material (e.g. perspex, aluminium) is preferable to minimise production of bremsstrahlung. In general, 10 mm of perspex is used to shield the most powerful beta emitters (1-10 MeV range) and to stop the formation of Bremsstrahlung. Several millimetres of aluminium will afford the equivalent attenuation.

Gamma and X radiation

X or gamma ionising radiation may be generated from its source as either a "broad beam" or a "narrow beam". In the case of a narrow beam, any scattered radiation is lost. In the case of a broad beam configuration, some scattered radiation may be brought back into the beam causing "buildup".

Narrow beam of radiations are attenuated exponentially:-

$$I_s = I_{\mu s}e^{-\mu t}$$

where $I_{\mu s}$ = Dose rate or count rate without shielding
I_s = Dose rate or count rate after passing through a shield of thickness (t)
μ = Linear absorption coefficient of the shielding material (length^{-1})

In the case of a broad beam configuration, a buildup factor (B) is included in the attenuation equation:

$$I_s = I_{\mu s}e^{-B\mu t} \qquad \text{for a broad beam source}$$

For shielding gamma and X radiation, high atomic number material (dense) is often used (e.g. lead, depleted uranium or tungsten). Lower atomic number material (e.g. steel, concrete or water) can be used but in correspondingly greater thicknesses.

The thickness of a particular shield that reduces the dose rate to half is termed the "half value layer" (HVL). The HVL is usually listed for various materials and various energies of radiation:

$$HVL = 0.693/\mu$$

e.g.

Material	HVL (cm)	Type of radiation

Lead	1.1	Cobalt-60 gamma
Iron	2.0	Cobalt-60 gamma
Concrete	6.3	Cobalt-60 gamma

The number of HVLs (N) may be determined by knowing the extent of attenuation:

$$Is = \frac{Ius}{2^N}$$

where Is = Shielded Intenstity
Ius = Unshielded Intensity

The tenth value layer (TVL) which gives the thickness of a material that attenuates dose by a factor of 10 is also sometimes useful:

$$TVL = \frac{2.303}{\mu}$$

The number of TVLs is given by:

$$I_s = \frac{I_{us}}{10^N}$$

Neutrons

The shielding of neutrons is complicated by the wide range of energies encountered. In the case of neutrons, it is best to try to make elastic scatter the predominant interaction mechanism with the shield. Consequently, it is best to use a shield made of light elements in order to avoid activation of the shield, e.g. Water, concrete, paraffin. The desired effect will be to slow the neutrons sufficiently to stop them.

If the shield is made of heavy elements (e.g. lead), then inelastic scattering or capture mechanisms may predominate, resulting in the activation of the shield material to a radioactive state that continues beyond the time of irradiation with neutrons.

Sometimes boron or cadmium are added to shielding materials as these elements have particular properties that make them good at attenuating neutrons. e.g. The boron rods used to control nuclear reactors.

Multiple source shielding requirements

The most common situation requiring shielding of two different types of radiation is that where beta and gamma isotopes are being used or stored together. In this case it is prudent to use a shield for the beta radiation closest to the sources (i.e. perspex or aluminium) and this should be followed by a shield suited to gamma radiation (e.g.

lead). Note that a reversal in the order of theses shielding materials in relation to the source may lead to the generation of Bremsstrahlung radiation.

14.3 Control Measures Specifically for Internal Radiation Hazards

14.3.1 Containment of Radioactive Material

The following suggestions should be considered:

- Use items of primary containment immediately around the source, e.g. Benchcote, floorcoat, trays and sumps.

- Use secondary containment around the primary containment, e.g. Smooth surfaces, fume hoods and glove boxes.

- Where an unsealed source of ionising radiation has become a contamination problem one of the following steps should be taken:

  For long-lived isotopes in a situation where the extent of contamination is known and cleanup may be performed safely, attempt cleanup by wet methods or use of high efficiency vacuum equipment.

  For short-lived isotopes where the extent of contamination is known but clean-up may be unsafe, cover the contaminated surface or cordon off and allow the radioactivity to decay away.

14.3.2 Cleanliness and Housekeeping

These aspects of a work area must be of the highest standard. As routine practice the work area should be checked for contamination before and after any work procedure and in any case, at least once per day.

14.3.3 Reduce the Use of Isotopes

Adopt a policy of using the smallest amount of the least toxic isotope suitable.

14.4 Administrative Controls

14.4.1 Precautions for Using Ionising Radiation

Procedures for use of ionising radiation should be formulated by the RSO and deputy RSO in accordance with AS2243.4 requirements.

14.4.1.1 Sealed Sources

Specific guidelines on safety measures to be adopted for use of sealed sources of ionising radiation should be taken from AS 2243.4 (1994), section 6.

14.4.1.2 Radiation producing apparatus

Specific guidelines on safety measures to be adopted for use of ionising radiation producing apparatus should be taken from AS 2243.4 (1994), section 6.

14.4.1.3 Unsealed sources

Specific guidelines on safety measures to be adopted for use of unsealed sources of ionising radiation should be taken from AS 2243.4 (1994), section 6.

14.4.2 Designated Radiation Areas

Where monitoring indicates that a person working in an area could receive three tenths or more of the exposure limit, such an area shall be classified as a DRA and shall come under the control of a RSO and deputy RSO. Most DRAs within Monash University are laboratories. They must comply with the stipulations of section 31 of the Policy Statement.

14.4.3 Radiation Warning Signs

The internationally recognised radiation warning sign (as shown in Figure 19) shall be displayed at the entrance to each DRA.

Figure 19:The Radiation Warning Sign

14.4.4 Controlled Areas

No radiation laboratory should allow automatic access to any non-radiation worker. All doors to laboratories should be fitted with locks and keys and these must be given only to those people who work in the laboratory.

14.4.5 Work Out of Hours

Work out of hours is not encouraged but if it must be done, compliance with section 27 of the Policy Statement is required. It is preferable to have a second person present.

14.5 Facilities in Radiation Laboratories

14.5.1 Grading of Radiation Laboratories

In order to ascertain the types of facilities required in a radiation laboratory, that laboratory should be graded in accordance with its proposed and current use. This should be done in accordance with Appendix B of AS 2243.4 (1994).

14.5.2 Design of Radiation Laboratories

Design features of any laboratory where ionising radiation is used should be based on section 11 of AS 2243.4 (1994).

There are also considerations in AS 2982 (Construction of laboratories). For further advice the RPO should be consulted.

15. STORAGE OF RADIOACTIVE WASTE AND SOURCES OF IONISING RADIATION

15.1 Introduction

This section should be read in conjunction with section 16 on management of ionising radiation wastes. Section 25 of the Policy Statement also contains relevant directives.

The major reasons for storage of sources of ionising radiation are:

- Sources that are no longer in use and are awaiting disposal.
- Sources that are in regular use but need to be controlled in order to avoid an incident as defined in section 19 of this manual.

Every department shall maintain its ionising radiation source inventory at a minimum and remove material that is no longer required by:

- Disposing of the low level waste without delay.
- Placing into short term storage in the medical or chemistry waste store, any material which is medium term waste and may be disposed of after a period of storage not longer than one year.
- Placing in the long term store any material that cannot be disposed of within one year.

15.2 Radiation Stores for Waste at Monash University

15.2.1 Monash Medical Centre

The hospital has its own store, which can only hold low level radioactive waste (see section 16.2) which is destined for immediate disposal.

15.2.2 Box Hill Hospital

The Monash Department of Medicine has its own storage facility for radioactive waste. Although space is extremely limited, it can hold some medium term waste.

15.2.3 Alfred Hospital

The hospital has its own store, which can only hold low level radioactive waste that is destined for immediate disposal.

15.2.4 Gippsland Campus

Does not have a dedicated radioactive waste store, as the usage (at present) of radioisotopes is limited to low activity emitters.

15.2.5 Caulfield Campus

Does not have a dedicated radioactive waste store as the usage (at present) of radioisotopes is limited.

15.2.6 Parkville Campus (VCP)

Does not have a dedicated radioactive waste store, as the usage (at present) of radioisotopes is limited to low level emitters.

15.2.7 Clayton Campus

There are two short/medium term stores in existence, which are cleared by a monthly collection. The keys to these are held by the RSOs and deputy RSOs of the user departments:

- Chemistry store

- Medical store

There is also now a long term radiation waste store managed by the RPO.

15.3 Labelling of Radioactive Sources for Storage

The requirement for labelling of short term waste that is destined for immediate disposal are set out in section 16. In the case of medium and long term waste or other ionising radiation sources requiring storage in any of the radiation stores mentioned in 15.2, a permanent label with the following information must be affixed:

- The department of origin
- Two persons responsible for the item
- Phone numbers for the responsible persons
- The radionuclide contained
- The activity contained and the maximum count rate on the surface of any container
- The dates of measurement of the activities given
- The date of deposition in the store

- The estimated date of disposal of waste

15.4 Containers for Storage of Radioactive Sources and Waste

Ionising radiation may induce decomposition of water. Hence, vented containers may be needed to store aqueous radioactive solutions. Thermally unstable radioactive solutions (e.g. nitric acid or other oxidising solutions containing traces of organic material peroxides or perchlorates), also need to be stored in vented containers. Bottles of old radioactive liquids should only be opened in a fume cupboard.

Acidic or alkaline waste should be neutralized before storage for any length of time.

Containers used to transfer radioactive materials to and from the store should be designed to prevent accidental release of the material if they are dropped or upset. Containers must be chemically resistant to their contents and not too heavy to lift. No container should hold more than 5 litres of liquid radioactive material.

15.5 Shielding for Long Term Radioactive Sources and Waste

"High level radioactive" waste (radioactive waste other than low level) must be contained according to its rate of decay. Accordingly shielding will be required to ensure that the dose rate on the inside of the store is no more than 5 $mSvh^{-1}$ due to all packages. The dose rate external to the store must be no more than 2.5 $mSvh^{-1}$ to conform with the public dose limit.

15.6 Storage of Radioactive Sources

All sources must be stored in secure locations. That is they should not be left in unlocked locations that may be accessed by non radiation workers.

16. DISPOSAL OF RADIOACTIVE WASTE

16.1 Introduction

Monash University policy on waste management is contained in section 25 on the Policy Statement. Further requirements are set out in part 12 of the Health (Radiation Safety) Regulations 1994, the NH&MRC Code of Practice for the Disposal of Radioactive Wastes by the User (1985) and AS 2243.4 (1994) Safety in Laboratories - Part 4 - Ionising Radiations (section 8). Storage of radioactive waste is dealt with in section 15 of this manual.

In all cases, the disposal and handling of radioactive waste must not result in any person becoming exposed to ionising radiation above the dose limits detailed in section 13 of this manual. The limiting exposure factor in handling waste is the radiation worker effective dose limit (which is effectively 5 μSv/h based on the 20 mSv limit). In addition, all waste handling procedures must satisfy the ALARA principle.

16.2 Types of Low Level Radioactive Waste

16.2.1Low Level Waste

Radioactive waste in this manual means “low level” radioactive waste. The International Atomic Energy Agency have provided the only definition of "low level waste". It is that waste produced by the use of radioisotopes in industry, medicine, research or by nuclear power operations. This category includes a negligible amount of long-lived radionuclides that have half lives greater than 30 years. It does not include large concentrations of radioisotopes that require handling and transportation behind gamma shielding, or ones that generate appreciable heat from radioactive decay.

State of Waste	Form of Waste
Solid	-Tissues, sharps, instrument and other non-flowing matter -Animal carcasses or pieces thereof
Liquid	- Bodily fluids - Contaminated water - Chemicals in the liquid state
Airborne matter	- Gases - Vapours - Dusts

Table 19: Types of low level waste generated at Monash University

16.2.2 High Level Waste

High level waste includes all radioactive waste that does not fullfil the low level waste definition. Types of high level waste at Monash University are almost exclusively in the form of sealed sources.

16.3 The Principles of Waste Disposal

16.3.1 Dilution and Dispersion

Liquid or gaseous radioactive waste may be diluted with water or air respectively and dispersed into the environment. Current limits for disposal of certain radionuclides in this manner are given in part 12 of the Health (Radiation Safety) Regulations 1994. These limits apply to each of the University's campuses as a whole. Consequently, the RPO should be consulted to determine the amount of activity that each department is entitled to dispose of.

16.3.2 Concentration and Containment

Long lived radioactive waste in any physical form may be concentrated and contained. In the case of radioisotopes with very long half-lives consideration must be given to the life of the container. As yet there is no national repository for long lived radioactive waste. Such waste should be stored in the University's long term storage facility at the Clayton campus.

16.3.3 Delay and Decay

Short lived isotopes with current activities above the limits that permit immediate disposal can be stored whilst they decay. These should be labelled in accordance with section 15.3 of this manual and stored in the long or short term radioactive waste store depending on the length of time until disposal.

16.4 Segregation of Waste

Quantities of radioactive waste should be kept to a minimum by segregating radioactive work areas from non-radioactive ones within a single laboratory. All laboratories, whatever their size, must have an organised waste segregation system that allows separation of the following:

Non-radioactive wastes:	This category may need to be further sub-divided into categories such as chemical and biohazardous waste. Such sub-division is beyond the scope of this manual.
Solid radioactive wastes:	For incineration For dumping to landfill For storage to decay further
Liquid radioactive wastes	For incineration For discharge to the sewerage system For storage to decay further

16.5 Packaging of Waste for Disposal

Radioactive materials having a dose rate on the surface of the package of >5 µSv/hr must be packaged, labelled and transported in accordance with the Code of Practice for the Safe Transport of Radioactive Substances 1990.

All radioactive waste must be double packaged and one of the layers shall be waterproof.

Solid waste intended for landfill should be packed into closed drums, multiple opaque plastic bags or multi-layer paper and plastic bags. A foot operated bin with a double liner is a very suitable waste receptacle for solid waste. All container types except metal and large glass bottles are suitable for incineration.

Syringe needles, pipette tips and any other sharp objects should be packed in closed, approved sharps containers so that they will not protrude from the packaging.

Animal carcasses or any putrescible waste must be double bagged as for solid waste and stored in a freezer until disposal.

Scintillation vials must be collected in sealable plastic buckets provided by the waste removal contractor.

Where danger from contamination on the external surface of the package exists, the package should be covered with an additional layer of packaging. When choosing a container for chemical disposal, the compatibility of the chemical with that substance should be taken into account. Waste should be disposed of frequently and individual containers should not be allowed to become too heavy to lift. It is good practice to choose containers with limited capacity.

16 6 Labelling of Waste for Disposal

Provided that the outer dose rate limit of 5 mSv/hr has been met there is no legal requirement to label the outside of the package indicating that it is radioactive. It is considered undesirable to do so. However, the inner packaging that is not visible must be labelled as radioactive. Note that the requirements for labelling of low level waste prior to disposal vary considerably from labelling waste for storage or transport.

All waste containers of radioactive material must be labelled with a perishable paper label showing the following details in order that the costs of waste disposal can be distributed by the RPO. Waste not labelled in this manner shall not be cleared by the RPO for removal.

Department:
Radionuclides:
Activity:
Description of contents:
Date of deposition:
Name of responsible person:

16.7 Disposal of Various Types of Waste

16.7.1 Solid Wastes

16.7.1.1 Disposal to landfill

Low level solid waste including animal carcasses is the only radioactive waste that is permitted to be disposed of at a municipal tip. The tip must be approved specially for the purpose and an approved procedure must be followed. These stipulations are laid down by the EPA, Victoria. The following limits apply to dumping solid waste to landfill:

Regardless of the radionuclides contained in the package, the maximum dose rate at the surface of the package must not exceed 5 μSv/h. This approximates on some of the mini monitor count rate meters to an upper limit of 200 counts per second. However, calibration of the each monitor is obviously important.

The maximum non-fixed external contamination shall be no more than;

- 4 Bq/cm^2 for all radioisotopes, except
- 0.4 Bq/cm^2 for alpha emitters having a half life greater than 10 days.

These limits must be checked by the generator of the waste prior to removal of the package from the campus.

- For radionuclides from the natural uranium or natural thorium decay series, including the parent uranium and thorium radionuclides themselves, no more than 250 Bq of each per kg of waste.

- For other radionuclides having a half life of 1 year or greater, 0.1 ALI

- For other radionuclides having a half life between 60 days and 1 year, 1 ALI

- For other radionuclides having a half life of 60 days or less, 10 ALI

All radioactive waste that is disposed of to landfill must be enclosed in two layers of packaging, of which at least one layer shall be waterproof. The most commonly used containers are plastic lined paper bags. Note that it is not acceptable, under any circumstances to dispose of sharps to landfill.

16.7.1.2 Disposal by incineration

The Environment Protection Authority has placed stringent requirements on the permissible levels of emissions from all types of incinerators, and gives guidance on what can be burnt and the temperatures appropriate for incineration. This includes uncontaminated animal carcases and bedding and some paper products.

Under no circumstances are flammable solids, sharps and vials containing organic solvents suitable for low temperature incineration. Glass vials with metal caps are **not** suitable for incineration due to the explosion hazard they present.

It is the responsibility of the generator of the waste to check that these levels are complied with prior to the waste leaving the laboratory.

16.7.2 Liquid Wastes

16.7.2.1 Disposal to landfill

It is not permissible to dispose of liquid radioactive waste to landfill in a tip due to the risk of seepage from the tip site to ground water or later earth works.

16.7.2.2 Disposal by incineration

Bulk solvents and liquid bio-hazardous matter that is contaminated with radioactivity are the most common types of radioactive waste incinerated. The rules for incineration of liquid radioactive waste are the same as those for incineration of solid waste. (See 16.7.1 above)

16.7.2.3 Disposal to the sewer

Low activity radioactive material may be discharged into a sewerage system, if the material is readily soluble and dispersible in water and:-

- the quantity discharged in any seven day period does not exceed 20 times the ALI by ingestion for that radionuclide; or

- the quantity discharged in any one period of 24 hours does not exceed the quantity which, if diluted by the average daily quantity of sewerage discharged into that system from those premises, would result in an average concentration equal to the appropriate maximum concentration permitted under section 73 Part 12 of Health (Radiation Safety) Regulations 1994.

- the quantity does not exceed that imposed by license conditions.

These limits apply to each of the University's campuses (i.e. Sites holding a licence for the use of unsealed sources). The RPO should be consulted if any site is unsure of the quantity of radiation it may dispose of.

Drains used for disposal of liquid radioactive waste shall be clearly and permanently labelled, and should not be connected to non-radioactive waste lines until outside the building.

Liquid radioactive waste discharged into laboratory sinks shall be diluted with copious amounts of water.

16.7.3 Airborne Wastes

Radioactive waste in the form of gases should be vented to a fume cupboard or local exhaust system and heavily diluted with air. It will be necessary to contact the RPO in order to ascertain the limits on emission that are required by law. Alternatively, radioactive aerosols may be contained by filtrations.

A contained area that is easily decontaminated and protects people in the vicinity (e.g. a glove box) is the best option. Fume cupboards or local exhaust will protect the operator but decontamination when maintenance work is required, is very difficult.

17. PROCEDURES FOR ORDERING, PURCHASING AND RECEIPT OF SPURCES OF INISING RADIATION

17.1 Introduction

The ordering, purchasing and receipt of sources of ionising radiation shall be carried out in accordance with the requirements of section 23 of the Policy Statement.

17.2 Ordering and Purchasing

All orders of sealed radioactive sources must include a list of officers authorised by the Head of Department to receive the goods.

Orders for unsealed sources by phone must be confirmed in writing. Written records must be kept of the order with a list of designated officers authorised to receive the consignment.

Labels (as below) are to be fixed to all consignments of radioactive sources, identifying the receiving department's name, names and phone numbers of at least two designated officers, who must receive the consignments when delivered. The laboratory manager then the RPO are to be contacted (and included as the last contact point) if none of the designated officers are available.

Department:

Authorised Officer's Name	Phone Number
1.	
2.	
3.	
4. RPO (OHSE)	9905 4019

17.3 Receipt of Radioactive Material

There must be a central or designated delivery point per department for the receipt of radioactive sources. The central or designated delivery point must have a separate clipboard with the list of names and contact phone numbers for designated officers authorised to receive radioactive consignments. Upon receipt of a radioactive consignment, a designated officer must sign the label on the package and the entry in the clipboard.

Security of radioactive materials must be ensured at **all** times. i.e. At no time are radioactive materials to be left unattended on loading docks or at a designated receiving point.

18. TRANSPORT OF RADIOACTIVE MATERIAL

18.1 Applicable Documents

Section 24 of the Policy Statement details Monash University policy for transport of radioactive materials.

The transport of radioactive material by road, sea or air and the storing, packing and stowing of that material in relation to transport is currently regulated by Part 11 of the Health (Radiation Safety) Regulations 1994. These call up the Code of Practice for the Safe Transport of Radioactive Substances 1990 (hereafter referred to as the "Australian Code"). This code is an Australia wide document in its application and is modelled on the International Atomic Energy Agency’s Regulations for the Safe Transport of Radioactive Material 1973 (hereafter referred to as the "International Code") which is an international document in its application.

For air transport of sources of ionising radiation the most current edition of the IATA (International Air Transport Association) Dangerous Goods Regulations should be consulted. These are the most stringent of all transport requirements.

18.2 Transport Guidelines in Practice

The IAEA Transport regulations form the basis of all Australian State legislation for the safe transport of radioactive materials. Section 11 of Health (Radiation Safety) Regulations, paragraphs 61, 62, 64 and 66 are particularly relevant.

The IAEA Transport Regulations are based on meeting four basic safety requirements:

- adequate containment of radioactive material;
- adequate shielding against the radiation emitted by the material;
- the dissipation of heat generated by high activity radioactive material;
- prevention of nuclear criticality when material is fissile.

The last two points will not apply to Monash University.

Packaging has been divided into five main types :

- type A;
- type B;
- low specific activity;
- low level solid;
- exempt.

Radioactive packages are classified into three categories based on the external radiation at the surface of the package and at a distance of 1m from the surface. The radiation level (mrem/h) at a distance of 1 meter from the surface of the package is referred to as the transport index. The three categories are :

Category I White	Radiation level at surface <5 µ Sv/h and package not Fissile Class II or Class III.
Category II Yellow	Radiation level at surface between 5 & 500 µ Sv/h. , package not Fissile Class III. Transport index <1.0.
Category III Yellow	Radiation level at surface between 500 & 2,000 µ Sv/h. Transport index <10.

The above surface radiation levels have been adopted on the basis of safe operating experience. The transport index is used to control the number of packages that can be grouped together, to ensure that the external radiation levels from a group of packages do not exceed safety levels.

19. INCIDENTS INVOLVING IONISING RADIATION

19.1 Introduction

Monash University policy for accident and emergency response is detailed in sections 22 and 26(iv) of the Policy Statement. In addition, the Monash University "Policy on Incident Reporting Investigation and Recording" (OHS Policy No. 1/89) contains relevant information.

19.2 Definition of an Incident

An "incident" involving radioactive material is defined as any situation, whether intentional or not, where a source of ionising radiation is in an uncontrolled situation or the potential for unexpected exposure has existed or exists. Examples of this are:

- Exposure to personnel above the Monash University action levels for ionising radiation dose.
- Any spill of radioactive material.
- Theft or loss of sources of ionising radiation.
- Deliberate misuse of sources of ionising radiation.
- Unauthorised entry to an area where source/s of ionising radiation are being used or stored.
- Any factor that causes damage to a room (or its contents) in which a source of ionising radiation is located.

19.3 Emergency Procedure

The procedure for dealing with an emergency involving ionising radiation is as follows. It is the responsibility of the first able-bodied person on the scene to initiate the procedure.

1. Recognise that an emergency possibly involving ionising radiation and other hazards is occurring.
2. Put in place a simple barricade, notice or obtain assistance to prevent entry by unauthorised or unknowing persons.
3. Notify one of the following persons in order of priority. It then becomes the responsibility of this person to take charge of the emergency. The most suitable person

to take care of the emergency is usually the RSO, deputy RSO or the RPO. The RPO must be called in any incident that is assessed as "serious", "significant" or "lost time" (in accordance with the policy on incident reporting, investigating and recording), by those first at the scene.

- Immediate supervisor
- The RSO
- The Deputy RSO
- The Safety Officer
- The RPO
- The Resources Manager
- The Head of Department

The RPO is obliged to notify the Department of Health & Community Services, Victoria and the Police in certain circumstances.

4. The person in charge of the emergency may then elect to notify emergency services. i.e. the fire brigade or ambulance. The person in charge may delegate responsibility to a second person to fetch the departmental radiation emergency response kit (section 19.4).

5. Ascertain the type of hazards and the relative risks present and the personal protective equipment that will be required to stop the emission, assist casualties and perform the cleanup. In doing this the person in charge should try to answer the following points:

   a) Type of radiation hazard - i.e. Sealed, unsealed or irradiating apparatus. This has ramifications for prevention of a worsening situation, cleanup methods and personal protective equipment.

   b) Is it in conjunction with other types of hazards?
   e.g.
   · Biohazardous material
   · Toxic, flammable or explosive materials
   · Broken glass

   c) Personal Protective equipment required for those preventing a worsening situation, cleaning up or attempting a rescue.

   d) Likely area covered by the hazard and consequently the area that needs to be barricaded.

6. The person in charge should then ensure that persons going into the area are properly protected and that there are facilities for their decontamination. The following procedures should then be carried out:

    a) Prevent the situation worsening by containing sealed and unsealed sources or stopping irradiating apparatus.

    b) Rescue any casualties. They may need to be decontaminated prior to removal from inside the barricaded area. If decontamination is not possible quickly then they may need to be treated within the barricaded area.

    c) Initiate cleanup procedures in accordance with section 19.6.

7. The person in charge may order the removal of the barricade when contamination monitoring confirms that the level of contamination to areas is below the DWLs given in section 19.5.2 of this manual.

8. The victim of the incident or the person who first reported it is responsible for recording the incident in accordance with section 19.7 of this manual.

19.4 Emergency Equipment

Emergency equipment to assist safe handling of a radiation or contamination accident should be readily available and the RSO and Deputy RSO must know of its location.

The RSO should obtain a portable spill kit; these are commercially available. Other useful items that should be kept with the kit include, personal dosimeters, monitors suitable for measuring contamination, respiratory protection devices and protective clothing.

It shall be the responsibility of the RSO or Deputy RSO to maintain the kit in a condition ready for use at any time.

19.5 Specified Actions to be Taken by RSOs and Deputy RSOs for Particular Incidents

19.5.1 Exposure to Personnel above the Monash University Action Levels for Ionising Radiation Dose

The RSO or Deputy RSO should investigate the cause of the high exposure without delay, complete a minor incident form and provide the RPO with a written explanation. RSOs should be aware that the timing of reporting is critical in the case of a known or suspected exposure that exceeds 5 mSv in one week. The RPO **must** report all such exposures to the Health Department within 48 hours of their known or suspected occurrence.

The RSO or Deputy RSO must also check or arrange to have checked the extent of internal and/or external contamination sustained by the individual concerned where the type of incident makes internal contamination a possibility (see section 10).

External contamination may be measured using an appropriate count rate monitor. All clothing and any exposed flesh should be checked. In accordance with the Health (Radiation Safety) Regulations 1994, the following DWLs signal the requirement to decontaminate the individual and the clothing and contain the contamination, see section 19.6 of this manual:

Alpha emitting radionuclides: 1.0 X 10^3 Bq/m^2
Beta emitting radionuclides: 1.0 X 10^4 Bq/m^2

In the case of a serious incident any obvious injury should be treated prior to decontamination of the victim, where this does not present significant risk to emergency response personnel. Person(s) involved in such an incident shall be aware of contamination risk to themselves and shall participate in special monitoring programs as deemed necessary by the RPO.

To conform with the “Policy on Incident Reporting, Incident Investigation and Recording” any exposures recorded as being above the Monash University Action Limit (480 µSv/ 12 week exposure whole body dose, 1 mSv/week for extremities) should be reported as significant incidents.

When an accidental exposure (e.g. via spillage) of personnel is believed to be above **1mSv** this should be immediately reported as a Significant incident (see Para. 36 Stat Rules, Health (Radiation Safety) Regulations 1994).

19.5.2 Spills of Radioactive Material

The RSO or Deputy RSO should initiate the prevention of further spread of contamination, once it is safe to do so. All surfaces within the area should then be decontaminated to below 1DWL

The procedures given in section 19.6 of this manual should be used.

Small spills of radioactive material that present no radiological hazard to persons should be dealt with by the radiation worker under the guidance of the person in charge of the incident. Rubber gloves are the basic personal protection for spill handling.

Spills of liquids should be absorbed with blotting paper, paper towels or tissues. Dry materials should be carefully wiped up with absorbent tissues moistened in water.

Where the level of radioactive contamination cannot be reduced below the DWLs specified above the following action must be taken:

- In the case of immovable contamination where cleanup has already been undertaken, cordon off the area or cover it with a shielding material to prevent unnecessary exposure for the time that it takes for the radioactivity to decay to below 1 DWL e.g. A lead plate is put over a floor tile contaminated by gamma radiation.

- In the case of movable contamination where cleanup is not feasible due to the risk involved either; cordon off the area, or cover it with a shielding material to prevent unnecessary exposure for the time that it takes for the radioactivity to decay to below 1 DWL.

19.5.3 Theft or Loss of Sources of Ionising Radiation

In any case of suspected theft or loss of a source of ionising radiation the RPO must be notified. The RPO will then contact the Police and the Health Department of Victoria.

19.5.4 Deliberate Misuse of Sources of Ionising Radiation

The RSO or Deputy RSO shall make use of available options such as withdrawal of permission to use radioactive materials or provisions of disciplinary procedures. In this case, it will be necessary for the Head of Department to become involved.

19.5.5 Unauthorised Entry to an Area where Source/s of Ionising Radiation are Being Used or Stored

The RSO or Deputy RSO shall make use of available options such as withdrawal of permission to use radioactive materials or provisions of disciplinary procedures. In this case, it will be necessary for the Head of Department to become involved.

19.5.6 Any Factor Causing Damage to a Room (or its contents) in which a source of ionising radiation is located

Firefighting takes precedence over contamination control, but all reasonable efforts should be made to minimise the spread of contamination, particularly at the clean-up stage.

Officers of the attending Fire Brigade should be informed in advance of the possible hazards due to ionising radiation. This is the responsibility of the person in charge of the incident.

19.6 Decontamination

19.6.1 Introduction

The most important rule with decontamination is to weigh up the benefits of decontamination versus the risks of cleaning up of highly radioactive material. It may be more appropriate to wait for decay to render the material less radioactive, prior to starting a clean up. Specific items that are contaminated may be easily dealt with by disposal. Failure to adopt this approach may expose clean up personnel to unacceptable radiation doses.

Current radiation safety and environmental protection law prohibits the disposal of any type of radioactive waste to the sink except in very controlled situations. All waste generated by a decontamination exercise must be collected and the advice of the RSO or deputy RSO sought prior to disposal (see sections 15 and 16 of this manual).

19.6.2 Decontamination of Personnel

19.6.2.1 External decontamination

Initially, the first aid requirements of any contaminated personnel should be attended to. Contaminated clothing should then be removed and personal decontamination should begin as soon as it is safe for medical personnel to do so. It is important to reassure the patient before, during and after the procedure. Generally, decontamination should proceed outwards from the orifices and any wounds, as these represent the greatest risk of entry of radiation into the body.

Personal decontamination should be continued until monitoring shows that radioactivity is below the DWL given in section 19.5.1 unless there is a risk of contamination entering the bloodstream through roughening or breaking of the skin. It should be noted that some contamination has the ability to "reappear"(alpha particularly) some 24-48 hours after satisfactory decontamination. This is due to the contamination soaking into the spongy stratum corneum layer of the skin. Consequently, any decontamination procedure should include regular checks of skin contamination for several days after initial decontamination.

Eyes should be irrigated with water, saline solution (1 percent common salt solution) and then water again. A standard clean plastic wash bottle is a convenient applicator.

Contaminated wounds should be washed under a fast running tap and bleeding encouraged. If on the face, take care not to contaminate the eyes, mouth or nostrils.

Skin and hands should be given one of the following treatments (in order of increasing severity):

- Wash with soap and water and scrub lightly with a soft nail-brush.
- Wash and scrub with a detergent.
- Rub gently with a cotton wool pad soaked in a complexing agent (eg. Cetavlon).
- Place vaseline® or a similar skin cream over the area and cover it with tight fitting cling-wrap or a rubber glove (in the case of hands) for several hours, prior to washing.
- Wash with a solution of 5% sodium hypochlorite (household bleach). Use 1% solution for the face and neck and take extreme care around the eyes.
- As a last resort, immerse the hands in saturated potassium permanganate solution, allow to dry and remove stain with 5 percent sodium metabisulphite solution.
- Medical authorities may attempt surgical removal of contamination.

19.6.2.2 Internal decontamination

Initially, the mouth should be washed copiously with water. If this does not remove the contamination it should be washed several times with hydrogen peroxide solution (one tablespoon of 10% solution to a tumbler of water) followed by copious washings with water. The victim must not be allowed to swallow the contaminated saliva and washing solution.

Many drugs and chemical substances have been advocated in the past for reducing absorption or enhancing elimination of internally absorbed radionuclides. The Health Department of Victoria now only advocates the use of such substances in cases of extreme exposure (i.e. life threatening) and only after consideration of individual circumstances. No person should undertake to treat a victim for internal radioactive contamination without first consulting the RPO and the Occupational Health Physician.

19.6.3 Decontamination of Material Objects

Attempt all decontamination procedures in a fume hood if possible, in order to contain splashes and aerosols. The equipment should be dismantled as far as possible. Decontamination should be continued until monitoring shows that contamination is below 1 DWL (section 19.5.2).

19.6.3.1 Glass and porcelain

Wash with mineral acid (chromic acid cleaning solution or concentrated nitric acid), ammonium citrate, trisodium phosphate, ammonium bifluoride or detergents and rinse thoroughly, avoiding splashing. When the glaze on porcelain is broken, or when active solutions are heated to extreme dryness in glass, decontamination is very difficult and it is usually more appropriate to discard such items.

19.6.3.2 Metal objects

The following approaches may be used (where appropriate):

- Attempt initial decontamination with detergents and water.

- Use dilute mineral acids (nitric or a weak solution of inhibited phosphoric acid), a 10% solution of sodium citrate, or ammonium bifluoride. Care should be taken as some radioisotopes may become volatile upon reaction with acids. e.g. Iodine.

- Use hydrochloric acid only when all other procedures for stainless steel fail. Hydrochloric acid is good decontaminant because it removes some of the surface, although the procedure results in etching of the stainless steel, which makes it less desirable for future use. It has been demonstrated that brass polish is an excellent decontaminant for brass.

- Customised cleaning baths such as degreasers or ultrasonic baths may be used however they then may present a problem as a contaminated object themselves.

- Light sandblasting - only after discussion with RPO.

19.6.3.3 Plastic objects

Plastics may be cleaned with soap and water, ammonium citrate, dilute acids or organic solvents (as appropriate for the particular plastic). In the case of plastic protective clothing, it is often easier to avoid contamination by smearing PVC suits with barrier cream, which is then easily washed off in soap and water. Plastic suits should never be cleaned with solvents whilst being worn.

19.6.3.4 Decontamination of large surfaces

Floors and benches contaminated with radioactive material should be cleaned carefully as described below using care not to spread contamination.

If the contamination is loose and dry, use masking or adhesive tape to trap small areas of it. Never sweep dry radioactive contamination as a possible inhalation hazard may be created; a wet mop should be used. If a wet mop will not remove the contamination, proceed with a method suitable for the particular surface material. Some methods outlined below.

- Linoleum:

    Wash with a solvent to remove all traces of wax, being mindful of the possible hazards involved, namely inhalation of the solvent vapour and skin absorption of the solvent liquid. Attempt this process only after discussion with the RPO, as suitable personal protective equipment may be needed for prevention of solvent exposure.

    Kerosene, ammonium citrate solution or diluted mineral acids may also be suitable, but care should be taken not to dissolve sealing compounds around the edges and between cracks of the linoleum.

- Ceramic tile:

    Wash with a mineral acid such as inhibited phosphoric acid containing a wetting agent or ammonium citrate or tri-sodiumphosphate.

- Paint:

    Soap and water, 10% hydrochloric acid or a gel type paint stripper may be used.

- Concrete:

  Clean as for ceramic tile or use inhibited hydrochloric acid. If these measures fail, concrete must be removed.

- Wood:

  Wood must be planed. Avoid sanding as this may create a radioactive dust hazard.

- Asphalt: Treat as for concrete.

If these do not work then the contaminated material may need to be removed for disposal. Alternatively the area may be shielded until it decays if appropriate.

19.6.3.5 Decontamination of plumbing surfaces

The following procedures are recommended:

· Flush thoroughly with a large volume of water.
· Scour with a rust remover and flush thoroughly.
· Soak in a solution of citric acid prepared by adding 0.5 kg of acid to 4.5 litres of water and flush thoroughly.

19.7 Incident Reporting, Investigation and Recording

Where any incident involving ionising radiation occurs, the procedures set out in the Monash University "Policy on incident Reporting, Investigation and Recording" are to be followed with the following exceptions:

·The RSO and Deputy RSO will replace the Safety Officer.

·Investigation of such incidents should involve the RSO or Deputy RSO and possibly, the RPO.

·After the immediate supervisor and the RSO or Deputy RSO, the person to call in a radiation emergency is the RPO.

20. RECORD KEEPING

20.1 Introduction

Records are to be kept in accordance with Section 21 and Appendices 1 and 2 of the Policy Statement and in relation to requirements in the Health (Radiation Safety) Regulations 1994.

20.2 Personal Dosimetry Records

Radiation dose records for each person monitored shall be kept for a period of 50 years. Upon request they shall be made available for inspection by the individual staff member involved as well as the RPO, the Occupational Physician or Health Department of Victoria personnel.

The RPO shall maintain a central registry of records including the following details:

- Name of wearer
- Date of issue and return of dosimeter
- Type of dosimeter
- Dose recorded
- Effective dose recorded for each year

A summary of the radiation dose record shall be available to each radiation worker when he/she leaves the University.

20.3 Records of Area Surveys

Survey records from monitoring of levels of external radiation, surface contamination and airborne contamination must be retained for a period of 6 years in a register containing the following information and maintained by the RSO or deputy RSO:

- Date
- Areas surveyed
- Purpose of survey (e.g. surface contamination)
- Instrument used
- Results

20.4 Monitoring Equipment Calibration Records

Calibration information shall be kept by the RSO for the lifetime of an instrument or the lifetime of results that are generated by it; whichever is the greater length of time. The following calibration information is to be kept in a register and displayed on the instrument:

- Instrument name/number
- Serial number
- Calibration factor to be applied (if it exceeds ± 20%)
- Date calibrated
- Date next calibration required
- Calibrating officer/organisation

20.5 Licences and Registrations

Records of licences shall be kept in accordance with section 16 of the Policy Statement and administered by the RPO.

20.6 Inventory of Sources of Ionising Radiation

The RPO shall maintain an inventory of all types of sources of ionising radiation which contains the following information:

- Registration details (for all source types except unsealed).

  Registrations for sources of ionising radiation shall be administered in accordance with the requirements of the Department of Health and Community Services and section 16 of the Policy Statement. The RSO or deputy RSO shall be responsible for keeping all original copies of paperwork connected with the registration of individual sources for a period of at least 6 years after they are deregistered and disposed of. All registration certificates shall be kept on or with the source itself.

- Records to account for all sources of ionising radiation that are borrowed, lent, disposed of or purchased by Monash University or that change hands between University departments.

Complete records of receipt of radioactive materials shall be kept by the RSO or Deputy RSO and will include radionuclide identity, activity, chemical form, date of purchase and place of storage. The RPO must be provided with a summary of information on all sources of ionising radiation purchased with the permission of the RSO or deputy RSO.

- Details of usage of the source.

  The RSO and Deputy RSO shall keep records of the usage of all types of sources in a log book. For unsealed sources a record shall be kept of every fraction dispensed from the original stock and will include: an identifier for the stock solution, activity used, volume used, purpose, method of disposal and the time and date of taking the aliquot.

- An identifier for the stock solution.
- Activity used.
- Volume used - Time and date of taking the aliquot.
- Intended use of radionuclide.
- Method of disposal.

21. RESEARCH ACTIVITIES

21.1 Research Involving the Planned Irradiation of Humans

Section 28 of the Policy Statement sets out specific requirements for this type of research at Monash University.

The Health Act 1958 and the Health (Radiation Safety) Regulations 1994 control all uses of ionising radiation in Victoria. There are specific requirements relating to research projects involving the irradiating of Human Volunteers, that is, persons who do not receive a direct benefit, either diagnostic or therapeutic, from the administration of ionising radiation.

Two separate licences are required before any work involving the exposure of Human Volunteers to ionising radiation is allowed to commence.

1) Institution Licence:

> Under regulation 12 (1) (c), Health (Radiation Safety) Regulations 1994, an institution licence must be held by an institution carrying out research involving the irradiation of Human Volunteers. Monash University currently holds such a licence. The Institution Licence is an institution-wide licence and separate site licences are not required. Any Research group planning to undertake this sort of research must forward their project protocol together with dose information to the RPO, as Monash University must seek separate approval for each project from the Department of Health & Community Services. As with all other Institution and Site Licences, this was paid out of the General Manager’s budget.

2) Operator Licences:

> Under regulation 11 (q), Health (Radiation Safety) Regulations 1994, a licence is required by any medical or scientific researcher who wishes to carry out work involving the irradiation of Human Volunteers. Furthermore, condition 36.04 as applied to all licences issued to institutions carrying out research with Human Volunteers, requires that the principal investigator of the research team and any person who administers the ionising radiation **must** be holders of the appropriate Operator Licence.
>
> These licences are to be paid for by the department directly involved in carrying out the research.

These Licences are obtained from the Department of Health and Community services through the RPO.

Information to be provided to the RPO with all applications for licences:

- A detailed protocol of the project, including an account of the advantages to be gained from the research.
- A radiation safety assessment (usually done by the RPO).
- Evidence that the project has been approved by the institution’s ethics committees (eg. Bioethics). To facilitate the approval process, applications may be made concurrently to the relevant ethics committees and the RPO.
- An estimate of the radiation doses expected to be delivered (whole body dose, specific organ dose), the biological half life of the radioisotope to be used and the risks associated with these doses. Include a copy of the calculations and references.
- The name of the principal researcher and the details of any person administering the ionising radiation and the routes of administration.

** The RPO must be notified when any research projects are completed, so that the Department of Health and Community Services can be informed and the projects removed from the licence.*

21.2 Research Involving the Administration of Ionising Radiation to Live Animals

Section 29 of the Policy Statement details Monash University policy requirements for the irradiation of live animals. In addition to this the following requirements shall apply:

- All projects shall have the approval of the Monash University Animal Ethics Committee prior to their commencement.

- Animal rooms and cages containing contaminated animals are to be posted with "CAUTION RADIOACTIVE MATERIAL" signs (see section 14.4.2), and the entrances to rooms restricted to authorised personnel.

- Authorised animal care personnel must be provided with appropriate personal protective equipment, radiation area monitoring equipment and personnel monitoring devices. Investigators must provide adequate instruction in the use of these devices. Periodic monitoring of the animals and rooms shall be made by investigative personnel instructed in the use of monitoring equipment.

Routes of metabolism and the form of excreted radio labelled material must be taken into consideration in regard to safe handling of animal bedding, cages, room surfaces, and room air. Plastic backed absorbent pads, plastic bags, and other items should be used in animal wards for containment of isotope spills or waste. Animal carcasses, contaminated bedding, and equipment must be surveyed for radioactivity and provisions made for decontamination or disposal.

The researcher is responsible for the proper disposal of radioactive wastes, decontamination of equipment, and the final decontamination of containment areas after each set of experiments. Dead animals must be placed in leakproof double walled plastic bags that are sealed prior to removal from the containment for disposal. Animal litter must be disposed of separately in a similar manner. They may require freezer storage until activity level has decreased.

It is preferred that animals given radioisotopes be housed in separate rooms by species and researcher. Special ventilation, surface preparation, drainage, or other room design requirements should be considered. To protect against undue radioactive contamination, all surfaces should be non-porous and easily washable. Cracks and crevices should be sealed. Continuous rubber or vinyl, or linoleum, applied over a floor will provide adequate protection, since these materials are non-porous and contamination must be able to be readily removed.

22. RADIATION SAFETY TRAINING

22.1 Non-radiation Workers

22.1.1 General

Non-radiation workers includes all staff and students who do not work with ionising radiation as part of their jobs but do work within departments where ionising radiation is used. Their training is the responsibility of the Departmental RSO and Deputy RSO, and should be done at the first available opportunity after their arrival within the department.

22.1.2 Type

The content of format and training shall be the first part of induction training as described in the Policy Statement.

22.2 New Radiation Workers

"New radiation workers" includes all staff and students within a particular department who have never been trained in the principles of ionising radiation safety. These people may be already working with radioactive substances or they may be intending to begin work shortly. As far as possible, the training must be done prior to commencing work with ionising radiation and is the responsibility of the RSO and Deputy RSO.

The format and content of training shall be the second part of induction training as described in the Policy Statement.

22.3 Experienced Radiation Workers

"Experienced radiation workers" includes all staff and students within a particular department who have undergone basic training as in section 22.2 and require additional specialist training for special applications of ionising radiation use. The training is the responsibility of the RSO and deputy RSO.

The content and format of the training shall be as detailed for radiation workers in the Policy Statement.

22.4 RSOs and Deputy RSOs

It is assumed that RSOs and deputy RSOs have completed training and are well versed with the principles taught in sections 22.1, 22.2 and 22.3. Training of the individual who holds this position is compulsory and must be repeated at least every five years. The training course is the responsibility of the RPO.

The content and format of training shall be as described for RSOs and deputy RSOs in the Policy Statement.

Glossary

Absorbed dose (D) - the energy absorbed by matter per unit mass of irradiated material. Averaged over a specific organ or tissue. The SI unit of absorbed dose is the Joule per kilogram. The special name is Gray (Gy).

Atomic number (proton number) (Z) - the number of protons in the nucleus of a particular element. It is equal to the number of electrons orbiting the nucleus of a neutral atom.

Activity (A) - the average number of spontaneous nuclear transformations of a radionuclide occurring in unit time. The SI unit of activity is the Becquerel (Bq), which is equal to one nuclear transformation per second. (See also Curie)

Acute - having a short and relatively severe course. A “short term” event or exposure. (See also chronic)

Adequate protection - protection against ionising radiations so that the radiation doses received by any person from external and/or internal sources are; as low as reasonably achievable (ALARA principle), and do not exceed the dose maxima referred to in section 4, AS2243.3.

ALARA - A basic tenet of radiation protection according to the ICRP. It states that exposures to ionising radiation must be **A**s **L**ow **A**s **R**easonably **A**chievable.

Alpha decay - emission of two protons plus two neutrons by a larger nucleus. The emitted foursome is called an alpha particle and causes a decrease in the *nucleon number of 4 and a decrease in the *atomic number of 2. (See also alpha radiation)

Alpha particle - a helium-4 nucleus emitted by a larger nucleus during the course of a radioactive decay known as *alpha decay.

Alpha radiation - a stream of alpha particles.

Annual limit on intake (ALI) - the activity of a radionuclide and any of its daughters which, if taken alone, would irradiate a person to the appropriate dose limit for either occupational or member of the public exposure as specified in Table 4.1 AS2243.3

Becquerel (Bq) - the SI name for the unit of activity; equal to 1 disintegration per second. (1dps)

The becquerel (Bq) replaces the Curie (Ci) which was defined as the activity of a radionuclide disintegrating at the rate of 3.7×10^{10} disintegrations per second. Thus 1 Ci = 3.7×10^{10} Bq and conversely 1 Bq = 2.7×10^{-11} Ci = 27 pCi.

Beta particle - a negatively charged particle emitted from the nucleus of an atom, during the conversion of a neutron to a proton (*beta decay)*. Beta particles produce ionisation by interacting with electrons in atomic or molecular orbits. They have a range higher than alpha rays and lower than gamma rays. Commonly used radionuclides, ^{3}H, ^{35}S, ^{32}P, ^{45}Ca, ^{47}Ca, ^{60}Co, and ^{137}Cs emit beta radiation. (See also "Bremsstrahlung" radiation).

Beta radiation - a stream of beta particles.

Bremsstrahlung (German "braking radiation") - The X- Rays emitted when a charged particle, especially a fast electron, is rapidly slowed down, as when it passes through the electric field surrounding an atomic nucleus. The X- Rays cover a continuous range of wavelengths, which depend on the energy of the incident particles.

Chronic - persisting over a long period of time. A "long term" event or exposure.(See also acute).

Committed effective dose - the effective dose that will be accumulated during the 50 years following the time of intake of radioactive material into the body.

Compound (molecule) - A group of atoms that are joined by chemical bonds. e.g. Water

Daughter/s - The product/s of radioactive decay of a radionuclide. e.g. Thorium-234, palladium-234 are both radioactive daughters of uranuim-238.

Derived air concentration (DAC) for occupational exposure- the ALI (of a radionuclide) divided by the volume of air inhaled by Reference Man (ICRP 60) in a working year. The unit is Bq/m^{3}

Derived Working Limit - The amount of radiation in terms of activity that when inhaled, ingested or absorbed is equivalent to 1 ALI.

Designated radiation area - an area where the occupational exposure of personnel to radiation or radioactive material is under the supervision of a RSO or deputy RSO

Deterministic effects - effects on a biological system in which the severity of the effect varies with the dose and for which there may be a threshold. Examples are non-malignant damage to the skin (radiation burns), cataract formation in the lens of the eye, and damage to blood vessels and connective tissue elements which are common to most organs in the body.

Detriment - the product of the probability of a deleterious effect and a measure of the severity of that effect on an individual. It is a complex function of the probability, severity and time expression of harm.

Effective dose (E) - the product of the equivalent dose (in a tissue or organ) and the tissue weighting factor (W_T) summed over all the tissues and organs of the body. The SI unit is the joule per kilogram, with the special name Sievert (Sv). (See also equivalent dose): $E = \sum W_T . H_T$

Electromagnetic radiation - energy resulting from the acceleration of electric charge and the associated electric and magnetic fields. The energy can be regarded as waves propagated through space (requiring no supporting medium) involving oscillating electric and magnetic fields at right angles to each other.

Electron capture - a radioactive transformation in which a nucleus acquires an electron from an inner orbit of the atom, thereby transforming initially into a nucleus with the same mass but atomic number one less than that of the original nucleus (ie a proton is transformed into a neutron). This type of capture is accompanied by emission of an X-Ray Photon as the vacancy of the inner orbit is filled by an outer electron.

Electronvolt (eV) -a unit of energy equal to the work done on an electron in moving it through a potential difference of 1 volt. It is used as a unit of particle energies. (NOT an SI unit). 1 eV = 1.602 X 10^{-19} joule.

Equivalent dose (H_T) - the product of the absorbed dose (averaged over a tissue or organ) and the radiation weighting factor (W_R) for the radiation under consideration. The SI unit is the joule per kilogram with the special name Sievert (Sv). (See also effective dose). $\boldsymbol{H_T = W_R \,.\, D}$

Equivalent dose enables the magnitude of exposures due to different types of ionising radiations to be compared directly with one another even though the biological effects of each type of radiation will vary in terms of severity.

Exposure - a measure of the X or gamma radiation at a certain place based upon its ability to produce ionisation in air.

External radiation - ionising radiation received by the body from sources outside the body.

Gamma radiation - a short intense burst of excess energy emitted by an excited nucleus after; α-decay, β-decay or electron capture. Common radionuclides, ^{47}Ca, ^{125}I, ^{60}Co, ^{137}Cs emit γ-rays. Gamma rays are electromagnetic radiation with high penetrating power. They have a long range and are less efficient in producing ionisation than α rays and β rays.

Glove box - a closed box, having impermeable gloves and viewing ports in one or more sides, which is used to completely enclose radioactive material and operations on the material.

Gray (Gy) - unit of absorbed dose of ionising radiation equal to 1 joule/kilogram.

Half-life - the period of time in which half the nuclei in a given sample of a particular radionuclide undergo radioactive decay.

Hereditary effects - biological effects of radiation that are transmitted to descendants of an irradiated individual as a direct result of damage to the genetic material within cells.

Internal radiation - ionising radiation received by the body from sources taken inside the body. Typically this occurs by ingestion, absorption or inhalation of radioactive material.

Ion - a positively (lost electrons) or negatively charged (gained electrons) entity . e.g. OH^- (hydroxyl ion) or H^+ (hydrogen ion).

Ionising radiation - electromagnetic or corpuscular radiation capable of producing ions directly or indirectly by its passage through matter. It includes radiations emitted by X-ray tubes and particle accelerators, radioactive materials and neutrons.

Irradiating apparatus - apparatus that is capable of producing ionising radiation, or of accelerating atomic particles.

Isotopes - Atoms having the same numbers of protons (i.e. same element) but differing numbers of neutrons in the nucleus.

Leakage radiation - all radiation except the useful beam coming from within a protective housing.

Linear energy transfer (LET) - a measure of the density of ionisation in a particular material along the path of travel of an ionising particle. Ionising radiations of low LET (X, gamma and beta) have low W_R values due to the small amount of ionisation that they cause in human tissue, compared with higher LET radiations (neutrons and alpha) which have high W_R values. Linear energy transfer is a function of the energy and velocity of a particular radiation.

Nucleon - a*proton or a * neutron

Neutron radiation - consists of fast or slow moving neutrons which are always derived from the nucleus of atoms. The neutron has a mass of one and is electrically neutral. Neutrons cannot produce ions directly. They can transfer energy to atomic nuclei by billiard ball type collisions and the resulting moving nuclei can produce ionisation. Neutrons can also get absorbed in atomic nuclei to produce nuclear reactions emitting γ-rays. Neutrons can induce radioactivity in surrounding material. Sources of neutrons are Californium-252, α-emitters mixed with beryllium and nuclear reactors.

Nuclide - a species of atom characterised by the composition of its nucleus, i.e. by the number of neutrons and protons in its nucleus. (See also isotope).

Positron - a positively charged beta particle emitted from the nucleus. It is the anti-particle of the electron.

Protective housing - a housing of an x-ray tube or of a sealed source intended to reduce the leakage radiation to a specified level.

Radiation - a stream of particles (alpha or beta) from a radioactive source. Also a stream of energy travelling in the form of electromagnetic waves or photons (eg X - or gamma-rays).

Radiation damage - harmful changes that occur to living organisms as a result of exposure to energetic electrons, nucleons, fission fragments or high energy electromagnetic radiation. Damage may be caused by electronic excitation, ionisation, transmutation or displacement of atoms. These mechanisms may cause damage to cells: alter their genetic structure, interfere with their division or kill them. These changes can lead to *radiation sickness or radiation burns* (from large doses of radiation).

Radiation laboratory - a laboratory in which irradiating apparatus or sealed radioactive sources are used or stored. It does **not** contain any **unsealed** radioactive material.

Radiation Weighting Factor (W_R) - a non-dimensional weighting factor used in radiation protection to weight the absorbed dose. It depends on the type and energy of the radiation incident upon the body.

Radiation worker - a person who, in the course of his/her employment, may be exposed to ionising radiation arising from his/her direct involvement with sources of such radiation.

Radical (free) - an atomic or molecular entity missing a single electron from an outer shell.

Radioactive contamination - the presence of a radioactive substance or substances in or on a material or on a place where it is undesirable or could be harmful. In the specific case of the human body, this contamination includes both external skin contamination and internal contamination.

Radioactive material - any substance that consists of, or contains any radionuclide, provided that the activity of such material is greater than 70 Bq/g, or such other value defined in relevant legislation.

Radioisotope - an isotope that is radioactive.

Radioisotope laboratory - a laboratory in which unsealed radioactive material is used or stored. It does **not** contain any irradiating apparatus.

Radiological hazard - the potential danger to health arising from exposure to ionising radiation; it may arise from external radiation or from radiation from radioactive materials within the body.

Radiological laboratory - a laboratory which incorporates the functions of both a radiation laboratory and a radioisotope laboratory.

Radionuclide - a species of atom which undergoes spontaneous nuclear transformation with the emission of corpuscular or electromagnetic radiations.

Radiotoxicity - the toxicity attributable to ionising radiation emitted by a radionuclide (and its decay products) incorporated in the human body; radiotoxicity is related not only to the radioactive characteristics of the radionuclide but also to its chemical and physical state and to the metabolism of the radioactive elements in the body or in an organ of the body.

Sealed source - any radioactive material that is firmly bonded within metals or sealed in a capsule or similar container of adequate mechanical strength so as to prevent dispersion of the active material into the surroundings under foreseeable conditions of use and wear.

Shell - an orbit around the nucleus of an atom at a certain energy level. It will be inhabited by one or more electrons.

Sievert (Sv) - the name of the SI unit of equivalent dose or effective dose it is equal to 1 joule/kilogram..

Somatic effects - biological effects of radiation observed in an individual who has been irradiated with large acute doses.

Stochastic effects - effects on a biological system in which the probability of an effect rather than its severity is regarded as a function of dose, without a dose threshold. The only examples are carcinogenesis and benign tumours in exposed individuals and hereditary effects in the descendants of exposed individuals.

Tissue weighting factor (W_T) - a non-dimensional factor used in radiation protection to weight the equivalent dose. It represents the relative contribution of each tissue or organ to the total detriment due to stochastic effects resulting from uniform irradiation of the whole body. (Tissue weighting factors are given in table A2, AS2243.4)

Unsealed source - a source which is not a sealed source and which under normal conditions of use can produce contamination.

Useful beam - that part of the primary and secondary radiation which passes through the aperture, cone or other device for collimating a beam of ionising radiation.

X-radiation - produced by bombarding atoms with high energy particles (eg electrons). All atoms emit a characteristic X- ray spectrum. X- rays are emitted when the incident electrons knock out an inner orbital electron and an outer orbital electron falls in to replace it, losing energy as it does so. (See also Bremsstrahlung).

Appendix A

Manual for Users of Ionising Radiation

MANUAL FOR USERS OF IONISING RADIATION

1. Introduction

The Manual for Users of Ionising Radiation is intended for use by radiation workers. It should be read in conjunction with the Monash University Ionising Radiation Policy Statement.

2. Responsibility for ionising radiation safety at Monash University

All individuals within a department that uses or stores ionising radiation are required to behave in a responsible manner and to obey safety instructions.

3. Types of Ionising Radiation

- **Particulate Radiation**

  Alpha radiation

  Particulate radiation consisting of slow moving, highly stable helium nuclei. Typically alpha particles travel only a few centimetres in air and only a few millimetres at the most within tissue or paper. Examples of alpha emitters are uranium-234, thorium-230, radium-226 and polonium-210.

  Beta radiation

  Particles consisting of fast moving very low mass electrons with a single negative charge. In general beta particles travel a few metres in air and a few centimetres in tissue. They have a range higher than most alpha particles and lower than most gamma rays. Some examples of beta emitting nuclides are; carbon-14, tritium (hydrogen-3), sulphur-35, calcium-45, phosphorous-32, and strontium-90.

  Neutron radiation

  Neutral, particulate radiation with a mass the same as a proton. In human tissue the average distance of penetration varies from 0.6 centimetres to nearly 10 centimetres depending on the energy of the neutrons. Californium-252 is an example (sufficient length of half-life) of an artificially produced radionuclide that spontaneously undergoes fission and subsequent emission of neutrons.

- **Electromagnetic Radiation**

Gamma radiation

Electromagnetic radiations consisting of photons of energy. Gamma radiation has the largest range of all radiation types. Gamma photons will travel indefinite distances unless intercepted by a medium consisting of atoms that will interact to take up the energy and extinguish the radiation. Gamma radiation will pass right through the human body and travel for many metres in air unless blocked by a suitable shield. Examples are Calcium-47, iodine-125, cobalt-60 and caesium-137.

X radiation

X radiation has travel ranges that vary enormously according to energy. It has the same properties as gamma radiation except that the range of travel distances tends to be larger. Examples of X ray sources are X ray machines and X ray diffractometers.

4. The interaction of ionising radiation with biological matter

- **Alpha radiation**

Alpha radiation does not present a significant external radiation hazard because it only has a range of several centimetres in air and is stopped by the outer layers of human skin. However, if taken inside the body alpha radiation presents the most serious internal radiation hazard of all because of its propensity for intense ionisation in a local area of tissue.

Nuclei that emit alpha particles are heavy nuclei. The chemical properties of such elements dictate that they are bone seekers and that they have long biological half lives. Consequently many alpha emitters have been associated with bone cancer.

- **Beta radiation**

Beta radiation rarely presents a large external hazard unless it is highly energetic (e.g. Phosphorous-32) and close to the skin, in which case it may cause injury to the outer layers of skin. If taken within the body beta radiation represents a significant internal hazard due to its ability to ionise the tissue in a localised area.

- **Gamma, X and neutron radiation**

Gamma, X and neutron radiation are most serious as external radiation hazards due to their ability to traverse large distances. They may cause injury to all areas of the body without much localisation. They do not represent the internal radiation threat that the particulate radiations do because much of the energy may pass through the body without causing any damage.

5. The Relative Effects of Specific Radiations on the body

Radiation weighting factors express the relative damaging capability of different kinds of ionising radiation. The higher the factor the greater the damaging capability of a unit amount of the radiation.

Type of Particle	Radiation weighting factor
X and gamma rays	1
Beta particles	1
Neutrons	5 - 20
Alpha particles	20

6. Susceptibility to the Effects of Ionising Radiation by different bodily tissues

Different tissues within the body show differing susceptibilities to the effects of ionising radiation. It is considered that those organs or tissues with the highest tissue weighting factors have the greatest susceptibility to ionising radiation.

ICRP Tissue Weighting Factors

Tissue or Organ	Factor	Comment
gonads	0.20	Most Sensitive
bone marrow (red)	0.12	
colon	0.12	
lung	0.12	
stomach	0.12	
bladder	0.05	
thyroid	0.05	
skin	0.01	Least sensitive
bone surface	0.01	Least sensitive

7. The biological effects of ionising radiation

7.2. The Effects of Ionising Radiation on the Human Body

- **Radiation sickness**

  An acute dose of approximately 1 Gy may result in nausea, vomiting, rapid pulse and fever just a few hours after the exposure. This is the direct result of damage to cells lining the intestine.

- **Death**

  It is accepted that acute doses of ionising radiation above 2 Gy have a reasonable probability of early death for the individual concerned. A dose in the range of 3-10 Gy results in the victim usually dying of secondary infection within a few weeks.

- **Cancer**

  This may occur in almost any organ in the body and its initial location is dependent on the type of radiation, the isotope and the area of the body that is exposed. The mechanism of cancer induction is believed to be a direct result of the ionising potential of radiation. The main examples of cancers that may be induced by exposure to ionising radiation are shown below.

Cancer	**Tissue at risk**	**Examples of "high" risk populations**
Leukemia	Red bone marrow	Children atomic bomb survivors
Lung Cancer	Lung	Uranium mine workers
Thyroid cancer	Thyroid	Users of iodine-125
Bone sarcoma	Cells on bone surface	Women painting luminous clock dials

- **The Skin**

  Ionising radiation will cause severe reddening of the skin and temporary depilation after approximately 3-5 Gy as an acute dose. Basal cell and squamous cell carcinomas, but not melanoma (the most dangerous of all skin cancers), have been associated with exposure to ionising radiation. It is known that exposures to the skin in excess of 10 Gy carry a significant excess risk of skin cancer.

- **Haematopoietic System (blood and blood forming organs)**

  The threshold of significant depression on the blood forming process for an acute dose given to the whole bone marrow is 0.5 Gy. The dose rate threshold for protracted exposure over many years is something more than 0.4 Gy per year.

- **Eyes**

  The lens of the eye is prone to developing cataracts after irradiation. Neutrons have been shown to have the greatest damaging ability. The general threshold that is given to avoid visual impairment in the case of occupational exposures which are highly fractionated and protracted, is a maximum of 0.15 Sv per year.

- **The Reproductive System**

  The germ cells of both sexes are more highly radiosensitive than other reproductive cells. All effects of sterility on the germ cells are early, somatic and deterministic.

- **The Thyroid**

  Functional thyroid damage ensues when the whole of the organ is exposed to doses in excess of 25-30 Gy fractionated over 30 days.

The Effects of Ionising Radiation on the Unborn Child

The effects of ionising radiation on the unborn child depend almost entirely on the stage of foetal development. Up to 3 weeks after conception the effect of even a small, acute radiation exposure (such as 0.1 Gy) may be an undetectable death and purging of the embryo. Higher doses during later stages of the pregnancy may induce the same effect.

During the third week the period of organogenesis begins. From this time until the end of major organogenesis at start of the ninth week after conception, the embryo is vulnerable to malformations in any organ under development at the time of exposure. Such malformations are estimated to have a threshold of 0.1 Gy in human beings.

Throughout the period commencing 3 weeks after conception and ending at birth the unborn child may be susceptible to an increased probability of cancers or leukemias that are expressed in the first decade of life. Estimates of the doses required to increase this probability are unavailable at this time.

During this same period the brain of the unborn child seems particularly vulnerable. IQ may be affected in a direct relationship with increasing dose.

8. Sources of exposure to ionising radiation at Monash University

8.1. Man Made Sources of Ionising Radiation

- **Irradiating Apparatus**

  Irradiating apparatus includes the following:

  X ray machines for diagnostic, therapeutic and industrial radiography.
  X ray fluorescence and diffraction instruments
  Miscellaneous equipment including electron microscopes, cathode ray tubes, high voltage electronic rectifiers and television screens which all produce small amounts of low energy X radiation. These are generally considered to constitute a minor source of X rays.

- **Sealed Sources**

  Some examples of the sealed sources held by Monash University, their activities and their uses are listed below

Source	Activity	Use
Cobalt-57	1110 MBq	Mossbauer research
Caesium-137	6 GBq	Research involving the biological effects of radiation
Americium-241	7.4 GBq	Teaching
Carbon-14	37 kBq	External calibration of liquid scintillation system
Iodine-129	31 kBq	Gamma reference source for equipment

- **Sealed Source Apparatus**

  Sealed source apparatus contain one or more sealed radioactive sources installed in a housing which prevents or minimises exposure of the users to the apparatus. Some of these sources are listed below.

Source	Activity	Use
Radium-226	370 kBq	Calibration of a beta counter

Europium-152	740 kBq	Calibration of a beta counter
Nickel-63	555 MBq	Calibration of an electron capture
Iron-55	370 kBq	Source of soft X rays in an instrumental analysis

- **Unsealed Radioactive Material**

  Unsealed sources are not contained in the same manner as a sealed source. They will readily produce contamination if handled inexpertly. Some of the wide variety of unsealed radioactive nuclides used at Monash University are listed below.

Radionuclide	**Typical use/carrier material**
Iodine-125	Carrier free or in iodinated peptides
Sulphur-35	Steroids, sulphuric acid
Hydrogen-3	Steroids, prostaglandins, peptides
Carbon-14	Steroids, saccharides
Phosphorus-32	Fatty acids

- **Radioactive Fallout**

  The radiation dose to Australians due to radioactive fallout may be directly attributed to the mankind's activities with radioactive materials such as; atomic bomb use and testing, accidents in nuclear power plants and incorrect disposal of airborne nuclear material. Some of the major radioisotopes are, plutonium-239, carbon-14, strontium-90 and caesium-137.

8.2. Natural Sources of Ionising Radiation

- **Cosmic Radiation**

  Cosmic radiation comes from the sun and its intensity varies with altitude. For example at Sydney (sea level) exposure due to cosmic radiation is approximately 300 mSv per year.

- **Terrestrial Radiation**

  Exposure from terrestrial radiation comes mainly from the ground and building materials. Radio isotopes such as potassium-40, uranium-23 and thorium-232 are common constituents of soils and building materials.

Isotopes such as these give all people radiation exposures that vary between 200 μSv and 25,000 μSv per annum depending on soil and rock composition in the geographical area.

9. The level of risk in relation to the use of ionising radiation

The Risk of Radiation Work Versus Other Work

Studies have shown that the total risk for the radiation worker population is equal to that for a non-radiation worker population which had a fatal accident rate of $35 - 50 \times 10^{-6}$ per year. In other words, the 2 mSv of occupational exposure to ionising radiation encountered by radiation workers had added between 10 and 25 fatalities per million radiation workers at risk. This fatality rate is still less than many non-radiation industries: e.g.

Industry	**Fatality rate (per 10^6 workers per year)**
Ship Building	*113*
Metal Manufacture	*118*
Coal & Petroleum Products	*148*

10. Statutory requirements

Monash University follows the directives of the Victorian State Government in relation to ionising radiation. Many recommendations of the NH&MRC and Standards Australia are also followed.

11. Exposure to ionising radiation

11.1. Internal Exposure

Internal exposure to ionising radiation comes about as a result of irradiation of inner body tissues resulting from surface or airborne contamination which has come into contact with and entered the body. The order of significance of each form of radiation as an internal hazard is as follows:

α increasing
β ↑ internal
γ hazard
neutrons

It is the inadvertent release of unsealed sources (contamination) that poses the main threat as an internal radiation hazard. Such contamination may easily become incorporated in organs or tissues if it is not carefully controlled.

Major routes of entry into the body are:

- Inhalation through the lung
- Ingestion through the gut
- Absorption through the skin

11.2. External Exposure

External exposure to ionising radiation arises from sources outside the body. Sealed and unsealed sources and irradiating apparatus may all become external radiation hazards if not handled properly. The order of significance of each form of radiation as an external hazard is as follows:

α increasing
β ↓ external
γ hazard
neutrons

The extent of severity of an external radiation hazard is related to increasing penetrating power of the radiation. In practice alpha radiation is not regarded as an external hazard because of low penetrating power.

12. Monitoring for ionising radiation

12.1. Introduction

The purpose of workplace radiation monitoring is twofold:

- Personal monitoring (monitor worn on the person) for the purposes of assessing the equivalent dose to the whole body or extremities.
- Area monitoring (monitor placed in a specific location/s) for the purposes finding contamination or assessing dose rates from specific sources of ionising radiation.

12.2. Types of monitoring

12.2.1. External dosimetry

Whole body dose

The whole body external exposure is measured using a film badge or a thermoluminescent dosimeter which is worn by the individual on the waist. Those who use neutron moisture meters should wear personal neutron radiation monitors.

The normal period of wearing for a whole body TLD is 8-12 weeks, except for pregnant women in which case it is 4 weeks. All persons working with ionising radiation (i.e. radiation workers), at the University will be required to wear personal monitoring devices.

Dose to Parts of the Body

Work in close proximity to radiation sources of small dimensions or with devices producing narrow beams of radiation, may expose a part of the body, particularly the fingers to high doses. "Finger TLD" dosimeters must be worn by staff working with phosphorus-32 unsealed source or x-ray diffraction x-ray fluorescence apparatus.

12.2.2. Internal Dosimetry

Thyroid monitoring

Monash University requires that all persons using radioactive iodine undergo regular thyroid monitoring every six months at least. If radioactive iodine is being used regularly, monitoring must be done monthly and immediately following any major task using the isotope. In the case of persons irregularly using radioiodine, thyroid monitoring should be done after each round of radioiodine manipulation.

Bioassay

Urine monitoring for tritium and carbon-14 beta emitters is the only bioassay monitoring commonly done at Monash University.

12.2.3. Area

Contamination on surfaces

The instrument most commonly used to measure radioactive contamination on surfaces is a count-rate meter. Note that there is no satisfactory simple instrument for the direct monitoring of tritium surface contamination.

Because both alpha particles and low-energy beta particles have very limited ranges in air, the detector must be held very close to, but not actually touching, the surface under investigation.

If inferences are to be made about dose using a count rate meter, then the meter must be calibrated in such a way that count rate can be related quantitatively to dose rate.

Wipe or smear testing

Wipe or smear testing should be used when direct monitoring is inappropriate. Examples of such situations are when monitoring for low energy beta emitting surface contamination (e.g. tritium or carbon-14), or the degree of removable contamination is to be estimated.

The procedure for wipe or smear testing should be discussed with your RSO or Deputy RSO. In brief, it involves wiping contamination onto a filter paper, counting the paper and comparing the result against the standard for surface contamination; the "derived working limit".

12.3. Types of Instruments for Measuring Ionising Radiation

You should become familiar with the monitoring instruments used by your laboratory. In brief, the various types are:

Count rate meters

These give a readout in counts per unit time. Note that count rate is not the same as activity. They are usually instantaneous readout instruments.

Dose rate meters

These give a readout in dose units (Sievert or Gray) per unit time. They work on the same basic mechanisms as count rate meters except that they sometimes include provision for distinguishing between different types of radiation. e.g. A sliding plastic plate across the detector to distinguish between alpha and beta radiation. They are instantaneous readout instruments.

13. Limits of acceptable exposure

13.1. The ICRP dose limits

ICRP Dose limit	
Application	**Occupational**
Effective whole body dose	20 mSv per year
Annual equivalent dose to:	
the lens of the eye	150 mSv
the skin	500 mSv
the hands and feet	500 mSv

A supplementary limit applies to protect the unborn child as a dose to the uterus can be taken to be the whole body dose to the embryo or foetus. This is an effective dose limit of 2mSv for the abdominal area for the remainder of the pregnancy.

13.2. Monash University Action Limits

The RPO has imposed action limits on external radiation exposures to university personnel. These action limits are also part of Monash University's Ionising Radiation Policy. The action limits are set at 10% of each ICRP dose limit. Any exposure above the action limit must be followed up by the RPO in association with the RSO or deputy RSO and the individual concerned, and a major incident form completed.

14. Control measures for ionising radiation

14.1. Preferred Control Measures

Removal

The most desirable option is to use an alternative to ionising radiation where possible.

Substitution

Substitution entails substituting a less hazardous radionuclide. Australian Standard 2243.4 should be consulted for the relative toxicities of radionuclides. Other factors such as volatility (e.g. radioiodines) may be a consideration.

14.2. Personal Protective Equipment

The last resort in preventing personal contamination and external exposure should be the use of personal protective equipment. Examples of personal protective equipment include:

- Lead aprons to shield external exposure for X and γ sources.
- Rubber gloves and overshoes to prevent personal contamination.
- Goggles or faceshields to protect against splashes.

14.3. Control Measures Specifically for External Radiation Hazards

Time

The total dose is directly proportional to the time of exposure.

dose = dose rate x time

Consequently time spent in an area where significant exposure may occur must be kept to a minimum.

Distance

Dose rate from gamma source is given by an inverse square law. In general people should stay as far away from radiation sources as possible.

Shielding

- Alpha radiation

  Alpha radiation does not require shielding due to its extremely low penetrating capability. It will be stopped by a sheet of paper, a few centimetres of air or the outer layer of human skin.

- Beta radiation

  For shielding beta radiation, low atomic number material (e.g. perspex, aluminium) is preferable to minimise the production of bremsstrahlung. Generally 10 mm of perspex will shield the most powerful beta emitters (1-10 MeV range) and stop the formation of bremsstrahlung. Several millimetres of aluminium will afford the same attenuation.

- Gamma and X radiation

  For shielding gamma and X radiation, high atomic number material (dense) is often used (e.g. lead, depleted uranium or tungsten). Lower atomic number material (e.g. steel, concrete or water) can be used but in correspondingly greater thicknesses.

- Neutrons

  The shielding of neutrons is complicated by the wide range of energies encountered. It is best to use a shield made of light elements in order to avoid activation of the shield. e.g. Water, concrete, paraffin. The desired effect is to slow the neutrons sufficiently to stop them.

  Sometimes boron or cadmium are added to shielding materials as these elements have particular properties that make them good at attenuating neutrons. e.g. The boron rods used to control nuclear reactors.

- Multiple source shielding requirements

  The most common situation requiring shielding of two different types of radiation is when beta and gamma isotopes are being used or stored together. In this case it is prudent to use a shield for the beta radiation closest to the sources (i.e. perspex or aluminium) and this should be followed by a shield suited to gamma radiation (e.g. lead). Note that a reversal in the order of theses shielding materials in relation to the source may lead to the generation of bremsstrahlung radiation.

14.4. Control Measures Internal Radiation Hazards

- ***Containment of Radioactive Material***

  A system of "primary" and "secondary" containment should be put around any source of ionising radiation that is liable to cause contamination. Use items of primary containment immediately around the source e.g. Benchcoat, floorcoat, trays and sumps. Use secondary containment around the primary containment e.g. Smooth surfaces, fumehoods and glove boxes.

- ***Cleanliness and Housekeeping***

  The cleanliness of a work area must be of the highest standard. As routine practice the work area should be checked for contamination before and after any work procedure and in any case, at least once per day.

- ***Curtail the Use of Isotopes***

  Adopt a policy of using the smallest amount of the least toxic isotope that is suitable for the task.

15. Disposal of radioactive waste

15.1. Segregation of Waste

Quantities of radioactive waste should be kept to a minimum by segregating radioactive work areas from non-radioactive areas within a single laboratory. All persons disposing of ionising radiation must consult with the RSO or Deputy RSO for an explanation of the waste segregation system. In brief waste must be divided up as follows:

Non-radioactive wastes:	This category may need to be further sub-divided into categories such as chemical and biohazardous waste.
Solid radioactive wastes:	For incineration For dumping to landfill For storage to decay further
Liquid radioactive wastes:	For incineration For discharge to the sewerage system For storage to decay further

15.2. Packaging of Waste for Disposal

All radioactive waste must be double bagged and one of the layers shall be waterproof.

Solid waste intended for landfill should be packed into closed drums, multiple opaque plastic bags or multi-layer paper and plastic bags. All container types except metal and large glass bottles are suitable for incineration.

Syringe needles, pipette tips and any other sharp objects should be packed in closed, approved sharps containers so that they will not protrude from the packaging.

Animal carcasses or any putrefiable waste must be double bagged as for solid waste and stored in a freezer until disposal.

Scintillation vials must be collected in closeable plastic 20 litre drums within the laboratory.

15.3. Labelling of Waste for Disposal

As long as the outer dose rate limit of 5 µSv/hr has been met there is no legal requirement to label the outside of the package indicating that it is radioactive. It is considered undesirable to do so. However the inner packaging that is not visible <u>must</u> be labelled as radioactive.

All waste containers of radioactive material placed within the radiaoactive stores must be labelled with a perishable paper label showing the following details. Waste not labelled in this manner shall not be cleared by the RPO for removal.

The minimum details required on the labels are:

Department:

Radionuclides:

Activity:

Description of contents:

Date of deposition:

Name of responsible person:

16. Incidents involving ionising radiation

16.1. Definition of an Incident

An "incident" involving radioactive material is defined as any situation, whether intentional or not, where a source of ionising radiation is in an uncontrolled situation or the potential for unexpected exposure existed or exists. Examples of this are:

Exposure to personnel above the Monash University action levels for ionising radiation dose.

Any spill of radioactive material.

Theft or loss of sources of ionising radiation.

Deliberate misuse of sources of ionising radiation.

Unauthorised entry to an area where source/s of ionising radiation are being used or stored.

Any factor that causes damage to a room (or its contents) in which a source of ionising radiation is located.

16.2. Emergency Procedure

The procedure for a radiation worker dealing with an emergency involving ionising radiation is as follows. It is the responsibility of the first able bodied person on the scene to initiate the procedure.

1. Recognise that an emergency possibly involving ionising radiation and other hazards is occurring.

2. Erect a simple barricade, notice or obtain assistance to prevent entry by unauthorised or unknowing persons.

3. Notify one of the following persons in order of priority. It then becomes the responsibility of this person to take charge of the emergency. The most suitable person to take care of the emergency is usually the RSO, deputy RSO or the RPO. The RPO must be called in any incident that is assessed as "serious", "significant" or "lost time" (in accordance with the policy on incident reporting, investigating and recording), by those first at the scene.

    - Immediate supervisor
    - The RSO
    - The Deputy RSO
    - The Safety Officer
    - The RPO
    - The Resources Manager
    - The Head of Department

4. The victim of the incident or the person who first reported it is responsible for recording the incident in accordance with section 19.7 of this manual.

16.3. Rules for Decontamination

The most important rule with decontamination is to weigh up the benefits of decontamination verses the risks of undertaking a clean up of highly radioactive material. It may be more appropriate to wait for decay to render the material less radioactive, prior to starting a clean up. Procedures for decontamination should be discussed with the RSO and Deputy RSO.

17. The Radioisotope Laboratory

17.1. Grading of laboratories

The hazard potential of a radionuclide depends on its radiotoxicity class, its activity, its chemical state and the laboratory manipulations undertaken. As the hazard potential increases so there is a parallel increase in the requirements for fittings and finish in the laboratory to maintain a safe work environment.

Three grades of laboratory - low, medium, and high level - have been defined for the use of unsealed radionuclide sources. Classification procedures are defined in AS 2243.4 (Standards Australia 1994a).

17.2. Radioisotope laboratory requirements

17.2.1. Low-level laboratory

For low-level laboratories, the work involves small quantities of radioactive material; few modifications are necessary in any modern conventional chemical laboratory. As always, a high degree of cleanliness is essential and suitable fittings and finish should be chosen. If practicable, the work should be confined to one or more suitably labelled benches set aside for radioactive work.

Horizontal surfaces should be covered with non-porous material. Floors should have smooth, continuous, non-absorbent surfaces - welded vinyl sheet is satisfactory. Tiles are not satisfactory as they shrink and leave gaps. Floors should never be cleaned by dry sweeping but by a wet process which minimises airborne dust. Walls and ceilings should have a non-porous washable surface such as high-gloss paint. Other surfaces liable to contamination should also be treated so as to give a satisfactory impervious finish.

Detailed requirements for a low level laboratory are given in AS 2243.4 (Standards Australia 1994a).

17.2.2. Medium-level laboratory

As set out in AS2243.4 (Int) 1994, medium-level laboratories shall be dedicated solely to radioisotope work. A typical procedure to be carried out in a medium-level laboratory is radio-iodination. The allowable activity of ^{125}I may be up to 200 MBq. The requirements for a medium-level laboratory are more stringent than for a low-level area. These requirements are detailed in Section 11.6.2., AS2243.4 (Int) 1994.

17.2.3. High-level laboratory

The high-level laboratory must provide the requirements for low and medium levels plus additional requirements given in AS 2243.4 (Standards Australia 1994a).

17.3. Radioisotope laboratory practices

17.3.1. Shielding

The shielding requirements from beta and gamma emitters are summarised in table 1. functional shielding should be used during storage of the radionuclide and during its use in the laboratory.

Shielding for storage sites should totally enclose the source (i.e. interlocking walls, top and base). This is particularly necessary for harder gamma sources where photons could penetrate the laboratory's wall, floor or ceiling to produce fugitive exposure outside the laboratory.

Radiation emitted by source	Recommended shielding material
Beta	Perspex
Beta + gamma	Laminate of perspex (nearest source) + lead
Gamma, x-ray, Bremsstrahlung	Lead, steel, concrete

Table 1: Shielding material for beta and gamma sources

17.3.2. Working surfaces

Polyethylene sheet or a plastic-backed, absorbent bench cover minimises the effect of accidental spillage of active material. such a spill may be easily mopped up from the impervious surface of the laboratory bench. Porous surfaces (such as an untreated wooden bench) are not suitable for radiation work.

Any spilt material must be removed immediately it occurs. Failure to do this may result in further, and more serious, accidents. Tissues used for the clean-up should be held in sponge forceps to avoid contamination of the hands and must be placed in the radioactive-waste bin.

Stainless-steel or plastic trays provide an additional means of containment and all the radioactive manipulations should be carried out inside them. An initial light application of silicone polish or wax is recommended for reducing the penetration of spilled material into the surface of the tray. If there is a danger of dust hazard when the spilled radioactive material dries, the tray should be lined with plastic backed absorbent bench liner. The paper should be discarded as radioactive waste at the end of each experiment.

Depending on the chemical form of the contaminant and the nature of the surface, surface decontamination can be achieved with solutions of detergent, ammonium citrate, dilute dydrochloric acid or kerosene. Be very careful not to spread the contamination.

17.3.3. Contaminated apparatus

A medium-level laboratory must have a complete and exclusive set of apparatus always kept there. Carrier-free isotopes are very likely to become strongly adsorbed on to glassware, and it is frequently difficult or impossible to remove them. For this reason disposable plastic apparatus is strongly recommended, if its use is practicable. It is most important that disposable apparatus should be washed thoroughly before it is placed in the radioactive-waste bin.

Contaminated glassware must not be returned to the general laboratory glassware but should be immediately washed in water and then totally immersed in an appropriate laboratory detergent solution (e.g. R.B.S. 25 or DECON-90). If this habit of immediate treatment is acquired it will save a great deal of time by preventing radioactive material from drying on the apparatus and thus becoming much more difficult to remove. Care should be taken to ensure that radioactive material is not accumulated in the cleaning fluid.

If this procedure is unsuccessful, expert advice should be sought. Cleaning procedures which may result in the release of gaseous radioactive material must not be used because of the inhalation hazard.

Before being put away, each article which had been contaminated should be tested with a monitor, though it should be remembered that an external monitor will not detect contamination inside glassware by substances emitting very soft radiations. If contamination is still present, the apparatus must be recleaned until an acceptable level of activity is reached. At this stage, immersion in a solution of carrier - that is, the inactive form of the radioactive compound one is trying to remove - may be of value.

If it proves impossible to clean satisfactorily apparatus which is contaminated with a short-lived isotope, arrangements should be made with the radiation safety officer for suitable storage until an acceptable radiation level is reached. Typically, this might be in a bin of suitable composition, permanently labelled in paint, ‘Radioactive Apparatus - Do Not Remove Before Date on Label’.

Each article placed therein should be clearly labelled with the date of contamination, the isotope and the date on which the radioactivity will have decayed to a safe level.

17.3.4. Sinks

The sink in a radioactive laboratory should be made of stainless steel. The drainage system from the sink should be continuous, convey the liquid to the main drain and not connected to open channels or traps.

Before using for washing contaminated glassware, the sink should be carefully cleaned with a commercial cleansing powder to remove grease. Any traces of radioactive material released during the washing of glassware, etc. should be flushed away with adequate amounts of water. A rubber mat should never be used in the bottom of the sink as this interferes with the free flow of water down the waste pipe and leads to the accumulation of radioactive material in the sink itself and on the slime which is invariably present on these mats.

17.3.5. Gloves

The primary purpose of gloves is to prevent contamination of the skin and not to provide shielding, so thin disposable rubber gloves which allow greater dexterity are always preferable to thicker gloves.

If the dose of radiation to the hands is an important factor, remote handling methods must be employed.

Of equal or even greater importance to the wearing of gloves is their removal after the task is completed and the proper disposal of the gloves to prevent further contamination. The recommended technique for glove removal follows.

This procedure is such that the inside of the glove is not touched by the outside, nor is any part of the outside allowed to come in contact with the bare skin.

1. The gloves should be lubricated internally with talcum powder.

2. The cuff of each glove should be folded over, outwards, for 4 cm.

3. Put one glove on by grasping only the internal folded-back part with the other hand.

4. Put the second glove on by holding it with the fingers of the gloved hand tucked in the fold and only touching the outside of the glove.

5. Unfold the gloves by manipulating the fingers inside the fold.

6. Gloves should be thoroughly washed before they are removed.

7. Gloves should be removed so that they are inside-out after removal, and without touching the outside surface to either hand or the internal surface of the other glove.

17.3.6. Contaminated and general waste

The laboratory should contain separate solid waste bins for contaminated (radioactive) waste and for general (non-radioactive) waste. The contaminated waste bin must be clearly labelled and must be of a suitable shielding material (or, in the case of lead shielding, set inside a suitable shielding material). Disposal of contaminated waste is the responsibility of the radiation workers.

17.3.7. Protection of the eyes

The lens of the eye is susceptible to damage by radiation. Energetic β emitters (e.g. ^{32}P) are a particular danger in this regard. The temptation to look into the open neck of a vessel containing a radioactive substance must be resisted since, under certain circumstances, the radiation is canalised by the shape of the vessel. If it is essential to see into the vessel, a mirror should be used and, if necessary, the illumination increased.

In work with β sources, a tall shield of transparent plastic is recommended. The design should be such as to give shielding protection to the eyes, face and body (as well as clear vision in every direction). For β sources, the shield is made of 10 mm thick perspex or acrylic which totally stops betas.

For very low energy γ sources (e.g. ^{125}I), similar transparent screens are available in Pb-impregnated acrylic. The acrylic is 12 mm thick and has a lead equivalency of 0.5 mm. For ^{125}I such a screen provides 10^3 x attenuation of the 0.035 MeV gammas. Note that the attenuation of such screens is poor for higher energy gammas.

17.3.8. Evaporation of radioactive solutions

Extra precautions should be taken when heating a radioactive solution. Widespread contamination is caused by fine invisible spray from a liquid which is being heated, and the spread of contamination is much greater if the solution is boiled.

When it is necessary to evaporate a solution (and this should be avoided if possible), the solution should be placed in a closed system fitted with a condenser or in a rotary vacuum evaporator. If time permits, freeze-drying is probably the best method for concentrating a radioactive solution. Evaporation in an open system, if this is unavoidable, must be done in a fume cupboard and should be conducted at the lowest possible temperature on a water bath fitted with ceramic rings (for easy decontamination). Infra-red heating from above is preferable as a means of reducing the spread of contamination during evaporation

17.3.9. Opening of vessels containing radioactive substances

Radioactive solutions frequently come in rubber-capped bottles and the liquid is most conveniently removed (under sterile conditions if necessary) by means of a disposable syringe fitted with a long No. 0 hypodermic needle. Remember to insert a second needle for air balance as the solution is removed.

If sealed glass ampoules have to be opened and the absorbed dose rate at the surface is high, specialist advice should be sought.

A word of caution should be given about the possible occurrence of radiochemical decomposition of liquids leading to a build-up of pressure inside closed containers. This is a comparatively rare phenomenon and the issuing authorities usually take precautions against such decomposition; for example, by suitably adjusting the pH of the solution. Nevertheless, it is not completely unknown. For this reason, it is wise to open all sealed containers in a fume cupboard. For the same reason, it is not safe to seal up considerable quantities of material of high specific activity for long periods of time.

Consignments of radioactive powders are often enclosed in screw-capped aluminium containers, which should only be opened with suitable long-handled instruments in a manipulator box. A heavy steel cup keyed to fit the base of the aluminium containers is a useful accessory for holding the containers while opening.

Tests should be carried out to show (by use of a TLD finger badge) that the skin of the hands receives considerably less than the maximum permissible dose of radiation during these procedures.

17.3.10. Transfer of radioactive solutions

The transfer of aqueous radioactive solutions may be expediently carried out by means of a Pasteur pipette fitted with a thick-walled rubber teat. Solutions in volatile solvents are not so easy to handle by this method.

The pipette should never be filled so that the liquid reaches the part held by the fingers, and the initial pressure on the teat should be such that it is not necessary to continue to compress it in order to prevent the liquid being sucked into the upper part of the pipette or even into the teat. One or two preliminary attempts at filling should be made to enable one to judge the compression required. As an additional precaution it is advisable to suck up a small quantity of air into the end of the pipette.

After use, the rubber teat, which should not be contaminated, may be removed and immersed in water containing a little carrier. The pipettes should be wrapped in absorbent paper and discarded into the contaminated-waste bin or, if necessary, stored.

In order to avoid the danger of ingestion of radioactive material, a rubber teat should never be moistened with saliva to make it slip on to the pipette easily.

Apart from the ease with which radioactive solutions may be transferred with these pipettes, the method has the outstanding advantage of speed. If operations of this type are carried out quickly, the personal exposure is correspondingly reduced.

Liquid spills on a well-polished and scrupulously clean surface may often be completely retrieved with one of these pipettes.

17.3.11. Arrangements for cleaning

The responsibility for cleaning radiochemical laboratories must rest with the radiation workers. For low level laboratories (and medium level, under most circumstances), it is reasonable for untrained persons to clean under careful supervision provided that no radioactive experiments are in progress and the working surfaces are free of contamination.

Once again it is emphasised that ‘wet’ methods of cleaning must be used to minimise the generation of airborne contaminants.

Cleaning materials which are used in a medium or high-level laboratory should be segregated and reserved for that laboratory.

17.3.12. Precautions when working with small radioactive animals

Radiation work with animals produces some additional concerns, including the generation of contaminated dust. The following guidelines are provided:

- If possible a room or rooms should be set aside for radioactive animals. Ideally, the rooms should be arranged as a suite, with access from the main animal quarters.

- Short-term experiments with a small number of animals may be better undertaken in the radioisotope laboratory where the work can be conducted in a fume cupboard.

- Experiments should be planned to give a graduation of activity from one room to the next.

- Normal animal-house ventilation, 6-10 changes h^{-1}, should be adequate.

- The floor surface must be such that it can easily be decontaminated by hosing down; this must be done carefully and thoroughly in the radioactive rooms.

- All the waste materials associated with the experiments (faeces, bedding, carcasses, etc.) must be treated as radioactive and be disposed of accordingly. Metabolism cages which allow all the waste and droppings to be collected must be used and enough sawdust should be provided to absorb all the urine. Cages will have to be decontaminated after use and a lining of polyethylene on the base may simplify this procedure.

- Accidental contamination of animal workers may occur in several ways. For example, an animal may urinate while being handled, a scratch would may be inflicted and the skin of the animal (or the bars of the cage) may be contaminated. The strict code of personal hygiene, gloves and laboratory coat (routinely used in the radioisotope laboratory) must be maintained.

Safe and reasonable limits for the total quantity of radioactive materials in animals at any one time depend very much on the facilities available and on the experience, training and degree of supervision of animals handlers. Specialist advice should be sought for experiments involving more than 1 GBq ^{3}H, 10 MBq of most other isotopes, and any work with α sources.

17.4. Contamination and decontamination

17.4.1. Maximum levels of contamination

Contamination of laboratory surfaces or workers with radionuclides must always be kept at the minimum practicable levels (hopefully indistinguishable from zero) in keeping with the ALARA principle in radiological protection.

However, an operation definition needs to be established as to the maximum amounts of such contamination that would be tolerable. For the purpose of university requirements, table 2 lists the recommended maximum levels for radionuclide contamination in a radioisotope laboratory.

Contamination site	Group 1 radiotoxicity and other α emitters	All other radionuclides
Surfaces of active areas, articles within active areas, personal protective equipment.	1 Bq cm^{-2}	10 Bq cm^{-2}
Hands and feet, personal clothing, all other laboratory surfaces.	0.1 Bq cm^{-2}	1 Bqcm^{-2}

Table 2: Recommended maximum levels of radionuclide contamination

17.4.2. Assessment of contamination levels

Contamination is invariably the result of accidental release of radioactive material. Although a maximum may be stated for any particular isotope in terms of activity likely to produce a certain dose rate at a specific place, a measurement of this low dose rate is not possible by ordinary methods and is obviously out of the question in an emergency. A measure of contamination is therefore made as the number of counts s^{-1} recorded by a sensitive detector (calibrated for the radioisotope).

For β particles, X-rays, and γ-rays a sensitive Geiger-Müller counter is satisfactory, although in the case of β particles a thin window will be necessary to allow the β particles to enter the counting chamber. For α particles, a suitable scintillation counter is needed.

None of these instruments is a linear device and therefore the exact relationship between counts s^{-1} and activity depends on the isotope being measured. It is therefore strongly recommended that all contamination monitors be calibrated for each isotope being used in the laboratory. In most instances this can be done by holding the monitor at a known distance close to but not touching a filter paper which has a known quantity of the isotope absorbed onto it.

17.4.3. Decontamination procedure

Loosely attached radioactive material on the bench top and floor may be detected using the smear test. This consists of wiping a known area of the bench with a filter paper (with known smaller area) and monitoring the filter paper. Some authorities suggest that the paper should be damp or lightly oiled. If loosely held radioactive material can be removed in this way, the spread of the contamination may result if it is left without further treatment. Every effort should be made to eliminate it so that the activity on the filter paper is finally zero.

If persistent firmly attached activity exceeding the maximum figures in table 2 still remains on the bench top or floor, that part on which it is localised should not be used during the decay of the isotope. If the isotope is long-lived its permanent presence is intolerable and the affected area should either be removed or else covered with a screening material such as lead or concrete.

17.5. Common laboratory radioisotopes

17.5.1. Tritium (^{3}H)

Tritium is a pure β emitter, maximum energy 0.018 MeV. The very low energy β particle has a range of only mm in air. Hence there is no need for shielding for external radiation.

This extremely short range makes it almost impossible to monitor for tritium using conventional instruments. An airflow monitor which sucks in air is available for measuring airborne ^{3}H contamination. Surface contamination can be indicated by a wipe test or measured using a special ‘windowless’ monitor. Internal burdens are assessed by liquid scintillation counting of urine samples.

Tritium is a moderate radiotoxic nuclide (group 3), with effective half life in the body of 10 days. However, ingested ^{3}H in certain forms is a much greater biological hazard than tritiated water. Tritiated nucleosides (and to a lesser extent simpler organic molecules) may be incorporated into the DNA of actively metabolising cells, causing an increased genetic hazard for three reasons:

- incorporation into DNA increases the biological half-life;

- the low energy of the β emission means a very short range and ensures that all the radiation energy from a decay is deposited very close to that DNA; and

- actively metabolising cells are generally more radiosensitive than non-dividing cells.

From the point of view of ingestion hazard, tritiated nucleosides are approximately ten times more harmful than tritium in an inorganic form.

17.5.2. Carbon-14

Carbon-14 is a pure β emitter, maximum energy 0.156 MeV. The low energy β particles have a range of 25cm in air and are stopped by the outer skin layer. Hence, there is no need for shielding for external radiation.

^{14}C is detected by a number of counter types. ^{14}C is a nuclide of moderate radiotoxicity (group 3), with effective half-life in the body of 40 days. Carbon-14, like tritium, when in certain organic forms may be selectively concentrated in cellular DNA. The radiotoxicity of such compounds will be approximately ten times more harmful than ^{14}C in an inorganic form.

17.5.3. Phosphorus-32

Phosphorus-32 is a pure β emitter, maximum energy 1.71 MeV. This hard β emission has a 7-m range in air and represents a significant external radiation hazard.

Shielding with plastic is therefore needed. A thickness of perspex or acrylic of 10 mm is sufficient to stop all βs emitted from ^{32}P.

^{32}P is a nuclide of high radiotoxicity (group 2), with effective half-life in the body of 14 days. Additional care is necessary with this isotope since, if ingested, it concentrates in the bone and irradiates the bone marrow.

17.5.4. Sulphur-35

Sulphur-35 is a pure β emitter, maximum energy 0.167 MeV. The shielding and detection requirements are thus similar to those of ^{14}C.

The low-energy β particles from ^{35}S have a range of 30 cm in air and are stopped by the outer skin layer. Hence, there is no need for shielding for external radiation.

^{35}S is a nuclide of moderate radiotoxicity (group 3), with effective half-life in the body of 80 days.

17.5.5. Calcium-45

^{45}Ca has a weak β emission, maximum energy 0.257 MeV. The shielding requirements in place for ^{32}P are more than adequate for ^{45}Ca.

^{45}Ca is a nuclide of high radiotoxicity (group 2).

17.5.6. Sodium-22

^{22}Na emits a medium energy positron (0.55 MeV), a hard γ-ray (1.27 MeV) and two positron annihilation photons (0.511 MeV) per disintegration. Shielding needs to be appropriate for the hard γ-ray.

^{22}Na is a nuclide of high radiotoxicity (group 2), with an effective half-life in the body of 10 days.

17.5.7. Iodine-125 and Iodine-131

^{125}Iodine emits a very low energy, short-range β-particle (maximum energy 0.035 MeV) and a very low energy γ-ray (0.027 MeV).

For very low energy γ sources like ^{125}I, transparent screens are available in Pb-impregnated acrylic. The acrylic is 12-mm thick and has a lead equivalency of 0.5 mm. For ^{125}I such a screen provides 10^3 x attenuation of the 0.027 MeV gammas. Note that the attenuation of such screens is poor for higher energy gammas.

Low energy X and γ radiation is only poorly detected by G-M monitors. Appropriate scintillation detector probes are required for monitoring.

^{131}I emits a medium energy β (maximum energy 0.61 MeV) and a range of γ ray energies (majority 0.36 MeV, small percentage of 0.72 MeV). Shielding for ^{131}I needs to be appropriate for the highest energy γ emission.

Iodine as the free element is quite volatile and strict precautions must be taken to reduce the risk of inhalation. furthermore, the high capacity of the thyroid to absorb iodine selectively from the bloodstream results in these isotopes being even more hazardous biologically than their physical properties would appear to indicate. Both ^{125}I and ^{131}I are nuclides of high radiotoxicity (group 2), with an effective half-life in the body of 35 days for ^{125}I and 7 days for ^{131}I.

17.5.8. Strontium-90

Strontium-90 is one of the most radiotoxic of the elements of low atomic number because it can substitute for calcium in bone producing a long effective half-life in the body. ^{90}Sr has a very high radiotoxicity (group 1) grading and an effective half-life in the body of 18 years.

Specialist advice must be sought before the use of this isotope is contemplated.

17.5.9. α particle emitters

These elements are all in the very high or high-toxicity category. They are difficult to monitor and great care must be taken to prevent inhalation. Approval for the use of α emitters is only granted subject to the most stringent conditions of safety and disposal.

17.6. Monitoring

The importance of regular and systematic monitoring cannot be over-emphasised. For many experiments both monitoring of the environment and personal monitoring are necessary, but great care must be taken to ensure that the monitor being used will give a reliable measurement of the particular type of radiation which may be present.

Refer to AS 2243.4 (Standards Australia 1994) for details of recommended monitoring regimes.

Appendix B

Statutory Documentation for Ionising Radiation

RELEVANT CODES OF PRACTICE AND GUIDELINES FROM THE NH&MRC

- Notes on Medical Procedures for Radiation Accidents and Radioactive Contamination (1968)
- Code of Practice for the Safe Use of Radioactive Luminous Compounds (1971)
- Recommendations for exemptions from Licensing of Gaseous Tritium Light Devices (1975)

No. 1. Recommended Radiation Protection Standards for Individuals Exposed to Ionising Radiation (1980).

No. 2. Code of Practice for the Design of Laboratories Using Radioactive Substances for Medical Purposes (1980)

No. 3. Code of Practice for the Safe Use of Ionizing Radiation in Veterinary Radiology: Part 1 and 2 (1982)

No. 4. Code of Practice for the Safe Use of Radiation Gauges (1982)

No. 5. Recommendations Relating to the Discharge of Patients Undergoing Treatment with Radioactive Substances (1983)

No. 8. Code of Nursing Practice for Staff Exposed to Ionizing Radiation (1984)

No. 9. Code of Practice for Protection Against Ionizing Radiation Emitted from X-Ray Analysis Equipment (1984)

No. 10. Code of Practice for the Safe Use of Ionizing Radiation in Veterinary Radiology: Part 3 - Radiotherapy (1984)

No. 11. Code of Practice for the Safe Use of Soil Density and Moisture Gauges Containing Radioactive Sources (1984)

No. 12. Administration of Ionizing Radiation to Human Subjects in Medical Research (1984)

No. 13. Code of Practice for the Disposal of Radioactive Wastes by the User (1985)

No. 14. Recommendations for Minimising Radiological Hazards to Patients (1985)

No. 18. Code of Practice for the Safe Handling of Corpses Containing Radioactive materials (1986)

No. 22. Statement on Enclosed X-Ray Equipment for Special Applications (1987)

No. 23. Code of Practice for the Control and Safe Handling of Radioactive Sources Used for Therapeutic Purposes (1988)

No. 24. Code of Practice for the Design and Safe Operation of Non-Medical Irradiation Facilities (1988)

No. 25. Recommendations for Ionization Chamber Smoke Detectors for Commercial and Industrial Fire Protection Systems (1988)

No. 26. Policy on Stable Iodine Prophylaxis Following Nuclear Reactor Accidents (1989)

No. 27. Australia's Radiation Protection Standards (1989)

No. 28. Code of Practice for the Safe Use of Sealed Radioactive Sources in Borehole Logging (1989)

No. 31. Code of Practice for the Safe Use of Industrial Radiography Equipment (1989)

No. 32. Intervention in Emergency Situations involving Radiation Exposure (1990)

No. 33. Interim Statement on Australia's Radiaiton Protection Standards (June 1991)

No. 39. Recommendations for Limiting Exposure to Ionising Radiation (1995) (Guidance note [NOHSC: 3022 (1995)]) and National Standard for limiting occupational exposure to ionising radiation [NOHSC: 1013 (1995)]

2 AUSTRALIAN STANDARDS

AS2243.4 - 1994(int): Safety in Laboratories- Part 4- Ionising Radiatons

AS2982 - 1987: Laboratory Construction

AS2243.8 - 1992: Safety in Laboratories - Part 8, Fume Cupboards

Appendix C

SAMPLE CALCULATIONS ON IONISING RADIATION

1. Convert an activity of 5 MBq to Curies

Information:

Use: 1 Curie = 3.7×10^{10} Becquerel

Solution:

$$\therefore \quad \text{Curies} = \frac{5 \times 10^{6}\ \text{Bq}}{3.7 \times 10^{10}\ \text{Bq}}$$

$$= 0.00014\ \text{Ci} = 140\ \mu\text{Ci}$$

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2. What is the activity of 40 GBq of ^{99m}Tc after 24 hours?

Information:

Use: n (no. half lives) = $\frac{\text{Total time}}{T_{½}\ \text{(half time)}}$

$T_{½}$ of ^{99m}**Tc** = 6.01 hours

A_t (Activity at time t) = $\frac{A_o\ \text{(initial activity)}}{2^{n}}$

Solution:

$$\therefore \quad n = \frac{24\text{hr}}{6.01\text{hr}}$$

$$= 3.99 \quad = \sim 4$$

$$A_t = \frac{40 \times 10^{9}\ \text{Bq}}{2^{4}}$$

$$= 2.5\ \text{GBq}$$

3. What is the unshielded dose rate 3 metres from 100 GBq source of ^{137}Cs?

Information:

$$DR = \frac{\Gamma \text{ x } A}{d^2}$$

Γ for ^{137}Cs =84μSvh^{-1} and represents the exposure rate 1 metre from a 1GBq source

Solution:

$$\therefore \quad DR = \frac{84\mu Svh^{-1} \text{ x } 100 \text{ Gbq}}{3^2}$$

$$= 933 \ \mu Svh^{-1}$$

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4. What thickness of lead shielding would be required to reduce a dose rate of 1867 μSvh^{-1} to 25 μSvh^{-1}?

Information:

Error! Bookmark not defined. $2^N \quad \frac{I_{VS}}{I_S}$
(1)

N (no. half value layers) = $\frac{t}{HVL}$ (2)

HVL for Lead for gamma rays of ^{137}Cs = 0.65 cm

Solution:

$\therefore$ Using (1) ln 1867 - ln 25 = N ln2
N = 6.224

Using (2) $6.224 = \frac{t}{0.65}$

t = 4.05 cm

5. 1 ml of iodinated (Iodine -125) inhibin, having a total activity of 0.5 mCi is to be couriered to NSW. In order to be exempt from some complex regulatory requirements one of the stipulations is that the dose rate on the outside of the package must not exceed 5 μSvh^{-1}. Assuming no shielding inside the package, what will the dimensions of the box need to be?

Information:

Assume: Point source in a cubical box of width, length and height 2r

Use: $$DR = \frac{\Gamma A}{d^2}$$

Γ = Specific gamma ray constant for I-125
= 2.7 µSvh^{-1} at 1m from a 1 GBq source (AS2243.4)
d = distance from source

Solution:

1 Curie = 3.7×10^{10} Becquerel

∴ Becquerels = $0.5 \times 10^{-3} \times 3.7 \times 10^{10}$

= 0.0185 Gbq

$$5\text{mSvh}^{-1} \text{ (at box surface)} = \frac{2.7\text{mSvh}^{-1} \times 0.0185 \text{ GBq}}{d^2}$$

$\Rightarrow$ d = 0.0999 metres

The box will need to be 2d wide, 2d high and 2d long. i.e. 20cm square.

6. A Monash department requires a lead lined box for storage of medium term ^{32}P and ^{125}I waste during its decay.

The annual total amount of these two isotopes that is used within the department is:

^{32}P 1μCi

^{125}I 1μCi

Using the assumption that all of this could end up in the box at once, what thicknesses of lead and aluminium are required to reduce the dose rate on the outer surface of the box to 0.5 μSvh^{-1} (in line with the member of the public dose limit of 1 mSv in any single year)?

Assume: The box will be fabricated from 2mm thick steel and it will have inner layers of lead and aluminium. Aluminium will need to be the inner most layer in order to avoid the generation of bremsstrahlung radiation. The box will be essentially full, with only 1mm gap between the packaged waste and any inner surface.

For ^{125}I:

Information:

$$N \text{ (no. half value layers)} = \frac{DR_{us}}{0.5\ \mu Svh^{-1}}$$

DR_{us} is the unshielded dose rate at any point 1mm on the inside of the box surface

$$DR_{us} = \frac{\Gamma \times A}{d^2}$$

Where: Γ for I-125 = 2.7mSvh^{-1}

A = 1 x 10^{-6} x 3.7 x 10^{10} Bq

= 37000 Bq = 3.7 x 10^{-5} GBq

d = 1mm = 0.001m

Solution:

∴ DR = 99.9mSvh^{-1}

$$\Rightarrow \quad N = \frac{99.9}{0.5} = 199.8 \text{ HVLs}$$

HVL for lead for I-125 gamma = 0.00037mm

∴ Thickness of lead required = 199.8 x 0.0037mm

= 0.74mm

i.e. ~ 1 mm

For ^{32}P:

Information:

The equation $DR = \frac{\Gamma A}{d^2}$ does **not** hold true

Instead we know that the effective range of ^{32}P beta radiation in unit density material is **0.8 cm**.

The density of aluminium at room temperature is **2.702 gcm^{-3}.**

Solution:

Hence the maximum effective range of ^{32}P beta radiation in aluminium is:

$$\frac{0.8}{2.702} = 0.3 \text{ cm}$$

Thus this is the minimum thickness of aluminium that needs to be used.

7. Calculate the absorbed dose received by the surface of the body from an unshielded 1MBq ^{32}P source at a distance of 0.5 m from the source.

Information:

^{32}P is a pure beta emitter with U_{max} - 1.71 MeV

$$\text{Absorbed dose rate} = \frac{1.5A \quad (U_{max1} + U_{max2} + \ldots)}{r^2} \quad \mu\text{Svh}^{-1}$$

A = *1MBq*
U_{max} = *1/81 MeV* *(AS2243.4, Table A3)*
r = *0.5 m*

Solution:

$$\therefore \quad \text{Absorbed dose rate} = \frac{1.5 \text{ x } 1 \text{ x } 1.71}{(0.5)^2}$$

$$= 10\ \mu\text{Svh}^{-1}$$