University of South Australia

Ionising Radiation Safety Manual

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Safety & Wellbeing Team

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Links to key documents and agencies

Radiation Protection Branch - Environment Protection Authority (EPA)

Radiation protection legislation and regulations:

- Radiation Protection and Control Act 1982
- Radiation Protection and Control (Ionising Radiation) Regulations 2000
- Radiation Protection and Control (Transport of Radioactive Substances) Regulations 2003

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)

Australasian Radiation Protection Society (ARPS)

Safety & Wellbeing website: **Ionising Radiation Policy**

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INTRODUCTION

This Radiation Safety Manual provides the framework for the operation of the Radiation Safety Program of the University of South Australia. It is important to recognise that the purpose of the Manual is not to contain specific operational instructions. These are contained in the Standard Operating Procedures (SOPs) relevant to the use of ionising radiation in the individual Schools.

This Manual is one element of the University Radiation Safety Program. It is the combination of training (including instruction in relevant SOPs), the SOPs themselves, the Radiation Safety Manual, the operations of the individual radiation workers, and the supervision and management of the Radiation Safety Program by the University Radiation Safety Officer and the Administrative Officer (Radiation), which will ensure that the members of the university and the public are not put at risk by the use of ionising radiation in the University.

The Manual is divided into eight parts and in most cases workers will need to be familiar only with the parts which are relevant to their operations.

Note: There are no pages 5 and 6

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PART 1 - AIMS OF THE RADIATION PROTECTION PROGRAM

The Radiation Safety Program at the University of South Australia is intended to minimise the possible effects of ionising radiation used in the university on staff, students and the general public.

The program includes meeting the legislative requirements, the implementation of the **ALARA** principle (As Low as Reasonably Achievable, economic and social factors being taken into account) at all levels, the setting of institutional standards, and training.

This Radiation Safety manual is part of that program.

1.1 POLICY

The Radiation Protection and Control Act 1982 and the Radiation Protection and Control (Ionising Radiation) Regulations 2000 control the use of ionising radiation in SA. Copies can be found on the EPA website at Radiation protection legislation and regulations. The Act and Regulations impose responsibilities on those who work with ionising radiation and their employers, and on those who own radiation apparatus or radioactive materials, or premises in which radioactive materials are used or stored.

The University of South Australia is committed to meeting the protection standards for ionising radiation set by legislation. Relevant Australian Standards are used as guides where appropriate.

In work with ionising radiation the **ALARA** principle (As Low as Reasonably Achievable, economic and social factors being taken into account) must be used to ensure that exposures to workers and the public are minimised.

Those supervising work with ionising radiation should hold the appropriate radiation licence, and consider the possible risks to themselves and others from the use of radiation and balance the risks against the expected benefits.

These goals are met by a combination of training, physical control measures, supervision and recording, under the supervision of the Safety & Wellbeing Team, the University Radiation Safety Officer, and the Department Radiation Safety Officers.

When staff and students of this University work with ionising radiations at another establishment, such as a research laboratory or hospital, they are required to read and follow the Radiation Safety Manual provided at that establishment in as far as there is no conflict with the Policy of this university. The Radiation Policy of this University is the minimum requirement for all radiation workers of this university no matter where they work.

1.2 RESPONSIBILITIES IN THE MANAGEMENT OF RADIATION SAFETY

The responsibilities of members of the University under the SA Radiation Protection and Control Act and associated Regulations are:

Vice-Chancellor and Council

The Vice-Chancellor and Council have the ultimate responsibility for meeting the requirements of the Occupational Health, Safety and Welfare Act, 1986,and Regulations, 1995 and the SA Radiation Protection and Control Act, 1982 and Radiation Protection And Control (Ionising Radiation) Regulations 2000.

Director: Human Resources

Ensures that the Manager: Wellbeing & Employee Benefits coordinates the management of ionising radiation safety in the University.

University Radiation Safety Officer

Reports to the Manager: Wellbeing & Employee Benefits and performs the duties required of the University Radiation Safety Officer. These duties in general are similar to those set out for a Radiation Protection Adviser in Australian Standard 2243.4 of 1998 and of a Radiation Safety Officer in the Ionising Radiation Regulations, and include advice, training, waste management and general supervision of radiation safety in the university.

Ensures, with the support of the Administrative Officer (Radiation) that radiation registration and licensing requirements are met, including the maintenance of records of registered radiation workers, of their exposure to ionising radiation, and of radiation incidents and accidents.

Heads of Schools and Directors of Research Institutes

Heads of School and Directors of Research Institutes have overall responsibility for the health, safety and welfare of staff, students and visitors in their areas of responsibility. They oversee the implementation of the University's policy and procedures on the use of ionising radiation and allocate adequate resources to ensure that the legislative requirements and University standards can be achieved. Managers and Supervisors have specific delegated responsibility for ensuring that the University standards are achieved in their areas of responsibility. Where ionising radiation is used, or radioactive material is stored, in their areas of responsibility they are to appoint a Department Radiation Safety Officer.

Department Radiation Safety Officers

The Department Radiation Safety Officer is the link between their areas of responsibility, such as a school or research institute, and the University Radiation Safety Officer and the University Administrative Officer (Radiation). They perform the function of Assistant Radiation Safety Officers described in the Regulations.

They must:

- ensure that radiation work in their area is carried out safely,
- provide appropriate training in radiation safety at a local level,
- the management of personal radiation monitors (TLDs) in their area,
- be informed prior to commencement of any new work or altered procedures involving radioactive materials or irradiating apparatus,
- be notified of any radiation incidents or accidents and direct decontamination procedures in the event of a major spill,
- have a responsibility for the initial management of radioactive waste in their area,
- in conjunction with the Radiation Safety Officer and Research Supervisors develop local emergency procedures and work rules. These are to be displayed in all areas where ionising radiation is used, and
- ensure that appropriate radiations signs are displayed in their areas, and accompany radioactive sources when being moved around and off-campus.

Research Supervisors

Research Supervisors, who are broadly defined as the equivalent of principal and associate investigators in grant applications, are ultimately responsible for the use of ionising radiation in projects under their control. They are responsible for ensuring that:

- those under their supervision receive appropriate training in radiation protection and are made aware of the risks associated with their use of ionising radiations,
- risk assessments have been undertaken and that appropriate contingency plans are in place,
- they are using appropriate work practices,
- they hold (or will obtain) an appropriate current radiation licence, and

- staff and graduate students under their supervision have completed a Radiation Worker Registration Form, which has been submitted to the Administrative Officer (Radiation) through the Department Radiation Safety Officer.

Staff, Higher Degree Students and Visitors

All persons using ionising radiation are responsible for their own safe use of ionising radiation and have an obligation to ensure that their work does not affect the safety of other staff, students or the public by any action or inaction. In particular, they must ensure that they do not expose others to radiation.

It is University policy that all coordinators of courses that involve the use of radioactive material or X-ray generating apparatus, in addition to the practical demonstrators, must hold the appropriate radiation license.

Each person working with ionising radiation at the University must:

- work in accordance with the Radiation Safety Manual,
- strictly observe guidelines in the Manual for exposure limits to radiation,
- properly use any personal monitoring devices (eg TLDs) issued to them,
- inform the Department Radiation Safety Officer through their supervisor in advance of any new work or altered procedures involving ionising radiation, and provide a description of methods, safety precautions and emergency procedures to be used,
- understand the chemical and physical properties, and possible biological effects, of the radiation or radioactive materials being used,
- reduce to a minimum the radiation hazard of the work,
- have a knowledge of appropriate accident and emergency procedures, and
- understand the regulations, codes of practice and local rules relevant to their work.

Undergraduate Students

The University has been exempted from the obligation to register as radiation workers undergraduate students working with ionising radiation in laboratory classes under close supervision. Special care must be taken when undergraduates use ionising radiation.

All work by undergraduates with ionising radiation must be under the supervision of a licensed demonstrator or instructor.

Laboratories where unsealed radionuclides are used by undergraduates, and any sealed sources used in undergraduate teaching, must be registered.

The quantities of radioactive materials used should be kept to a minimum and specific instruction on handling radioactive materials must be provided.

Undergraduates must not use X-ray generating apparatus unless they are adequately protected and the work is under continuous supervision.

1.3 THE LEGAL FRAMEWORK FOR CONTROLLING RADIATION HAZARDS

1.3.1 Licences, Registrations and Approvals

Licences

Generally the regulations require that individuals carrying out radiation work must be licensed but some exceptions are made. The following guidelines are to be followed in relation to licenses:

- the risks associated with the radiation hazard determine who should be licensed. The University Radiation Officer can provide advice on whether a person requires a license,
- at least one research supervisor (defined broadly as the equivalent of principal and associate investigators in grant applications), in projects in which ionising radiation is used, must be licensed. Licences are issued by

the Radiation Protection Division of the Environment Protection Authority (EPA), after sitting for an examination, and must be renewed annually,

- staff and students who work in a Type B registered premise must be licensed,
- those who work under supervision in Type C registered laboratories do not need to be licensed but their supervisors must be licensed. The supervisor is the person who has determined the nature of the work. Students, including graduate students, and technical staff are not usually supervisors,
- everyone who uses a sealed source must be licensed, and
- everyone who uses an X-ray generator (other than a fully enclosed or cabinet X-ray set) must be licensed.

Licence application forms can be obtained from the EPA website: Radiation licences - Industrial and Scientific. Assistance with the licence requirements and the examination syllabus is available from the University Radiation Safety Officer. Copies of new licences (including the Schedule printed on the back of the licence) should be emailed to the Administrative Officer (Radiation).

Registrations

Permanent sources of ionising radiation, such as X-ray generators and sealed sources of radioactive material must, unless an exemption has been granted, be registered.

Premises (rooms, laboratories etc.) in which unsealed sources of radioactive material are used or stored must be registered. These are classified according to the hazard, with Type C being the lowest hazard.

Registration application forms can be obtained from the EPA website: use Find a Document to get Radiation Forms. The Department Radiation Safety Officer must be informed of any applications for registration of rooms or equipment. Copies of new registrations should be emailed to the Administrative Officer (Radiation).

Approvals for disposal

Approval is required from the EPA to:

- dispose of radioactive waste in accordance with an annual plan
- dispose of an X-ray set or sealed radioactive source by sale, gift or decommissioning
- transfer unsealed radioactive material to another owner.

EPA submissions should be developed in liaison with the University Radiation Safety Officer. Approved plans should be emailed for central filing.

1.3.2 Worker Registration and Monitoring

Worker Registration

In addition to licensing and registration, the University must keep a register of all radiation workers. This is done through the Radiation Worker Registration file kept by the Administrative Officer (Radiation), Safety & Wellbeing Team.

All staff, visitors and higher degree students who are using ionising radiation must be included in the Radiation Worker Registration file. Supervisors must inform the Safety & Wellbeing Team when someone begins work with ionising radiation and the worker must complete and return the registration form through the Department Radiation Safety Officer. Information supplied in the Worker Registration form is confidential.

The University Radiation Safety Officer ensures that registered workers are informed of any need to obtain a licence, wear a personal dosimeter or attend suitable training.

Personal monitoring

The Regulations require the monitoring of the radiation dose of all registered workers. The University has an exemption from this requirement for undergraduate students.

Note: *An exemption from this requirement is granted where no simple personal monitoring devices exist (low energy radiation) or where there is a very small risk that radiation workers will receive a radiation dose more than one-tenth of the annual limit for workers.*

People working with very low energy sources, such as tritium, carbon-14, and sulfur-35 and those with a very small chance of receiving a dose greater than 2 mSv in a year, are not normally issued with a monitor in most institutions in SA. This is determined by the type and the maximum quantity of radionuclide they are handling - for example, the maximum quantity of P-32 that may be used by a worker not being monitored is 40 MBq.

The University Radiation Safety Officer must be involved in all decisions on whether personal monitoring is needed. The personal radiation monitors (TLDs) are administered by the respective Department Radiation Safety Officers.

Personal radiation monitors are issued to users of X-ray machines and sealed sources because the risk of a significant dose is higher with these sources.

The rules for wearing personal monitors are set down by the supplier of the service (such as ARPANSA) and must be followed.

A personal monitor must never be worn by any person other than the person to whom it is issued.

Wearers of personal dosimeters are informed of the doses received through their Department Radiation Safety Officer.

1.3.3 Reporting and Records

The University is required by the Regulations to maintain records of:

- registered workers and the dose reports from personal monitoring,
- the licences held by staff and higher degree students,
- registered premises, sources and ionising apparatus,
- purchases and disposals of unsealed radioactive materials (the records are kept by the Department Radiation Safety Officers),
- the movements and locations of sealed sources (the register is to be completed by users and overseen by the Department Radiation Safety Officer),
- the safety checks of X-ray machines (records kept by the Department Radiation Safety Officers), and
- the disposal of any radioactive waste under the approved plan (records kept by the Department Radiation Safety Officers).

Copies of the records held by the Departmental Radiation Safety Officers are forwarded to the Administrative Officer (Radiation), through the University Radiation Safety Officer.

1.3.4 Accidents involving Radiation

Abnormal events involving radiation are classed, depending on the associated risk as emergencies (major), accidents (intermediate) and incidents (minor)

The University Radiation Safety Officer is required to investigate all abnormal events and report the details to the Radiation Protection Division, EPA. The procedures for reporting accidents are included in Part 7 of this Manual.

1.4 SPECIAL CIRCUMSTANCES

1.4.1 Pregnancy

The risk of ionising radiation causing detriment to the foetus is higher than the risk to the worker and the normal dose limit for a worker is therefore reduced during pregnancy.

The NHMRC (National Health and Medical Research Council) recommends the same level of protection for the foetus as for a member of the public. This is a maximum dose of 1 mSv in a year, which is equivalent to a limit of 0.75 mSv to the abdomen during the pregnancy.

In practice the doses to workers in the University are normally well below 0.1 mSv per year and the risk to the foetus is very low.

If a radiation worker becomes pregnant the following steps **must** be taken:

- the Safety & Wellbeing Team must be informed through the Administrative Officer (Radiation); this information is private and confidential,
- research supervisors should also be informed of the pregnancy, and
- the research supervisor must evaluate the work practices in conjunction with the pregnant worker in order to minimise radiation exposure during pregnancy.

1.4.2 Human Research

The exposure of human subjects to ionising radiation for the purposes of research (as distinct from diagnosis or therapy) is strictly controlled. **Explicit** permission must be received from the Radiation Protection Division, EPA, for every research project involving ionising radiation and humans. Some hospital ethics committees have been delegated the power to approve such research.

These special requirements for ionising radiation are in addition to any other ethical requirements and special justification is required.

A copy of all research proposals involving human subjects and ionising radiation must be sent to the University Radiation Safety Officer.

1.4.3 Entry to Registered premises by non-Radiation workers

The University requires that all people who are not radiation workers, (including staff, students and outside contractors) must obtain permission from the licensed supervisor of registered radiation areas before entry.

Such persons are considered by Regulation 14 (4) of the SA Radiation Protection and Control Act, 1982, to be “members of the public”.

1.4.4 Work in non-University premises, including overseas

The University is responsible for university staff and students using ionising radiation in premises owned by another institution, such as a hospital or non-University laboratory. These people must be recorded in the University radiation worker registration list and University policy on supervision, licensing and so on must be followed. In some circumstances appropriate joint supervision by University staff and staff of the other institution should be arranged.

1.4.5 Radiation Workers from other institutions

Radiation Workers from other institutions carrying out radiation work at the University of South Australia are required to adhere to the University of South Australia Radiation Policy as a minimum.

They must be provided with their own personal radiation dose monitors by their employer or, in the case of a post graduate student, by their home institution. They are also required to register as a radiation worker at the University of South Australia.

PART 2 – IMPORTANT CONCEPTS IN RADIATION PROTECTION

2.1 RADIATION QUANTITIES

The effects of ionising radiation are largely dependent on the radiation dose, or the amount of energy absorbed from the radiation.

The **absorbed dose** measures the energy **absorbed** per unit mass of the absorbing material from the radiation field. The absorbed **dose rate** is the **absorbed dose per unit time,** usually **per hour.**

The word **dose** is sometimes used instead of the more correct **absorbed dose**.

A more detailed account of radiation quantities and units is contained in Part 6.

2.2 BIOLOGICAL EFFECTS OF IONISING RADIATION

Ionising radiation is harmful to life because it acts at the molecular level on cells and their constituents. Absorption of energy from ionising radiation may result in changes to the molecules, destruction of cellular elements, and altered function or death of the cell.

At low doses, ionising radiation may cause cancers and possibly induce genetic defects.

At high doses, it can kill cells, damage organs, and cause rapid death.

2.2.1 Somatic and Genetic effects

The biological effects are

- **somatic** if they appear in the exposed individuals, or
- **genetic** (**hereditary**) if they appear in their offspring.

Somatic effects

These are the result of direct cell damage, such as the death of skin cells in erythema.

They are

- **acute** if they appear within a short time (hours or days) after the radiation exposure, or

- **delayed** if they appear a long time (months or years) after the radiation exposure.

The damage done by high doses of radiation normally becomes evident within hours or days, such as the death of the gastro-intestinal tract. Cancers take many years to appear. For instance, Leukaemia takes on average about 5 years to appear, while solid cancers take on average about 10 years.

Genetic effects

These are the result of damage to the DNA of germ cells and may possibly occur at low doses. The effects are only apparent in offspring and are difficult to observe, even in large populations, due to the large natural occurrence of genetic defects (1 in 10)

Hereditary malformations and diseases caused by genetic damage may, if they occur, take generations to show in the descendants of those irradiated. Todate, no genetic effects due to radiation exposure have been observed in humans.

2.2.2 Medical (Somatic) effects

These may be classified into two types of effects:

Deterministic effects

These effects will occur when a threshold dose is exceeded, after which the severity of the effect increases with the radiation dose. These are produced by relatively high doses. The effects vary considerably from one organ to another. Low doses cause interference with the correct functioning of an organ without necessarily killing it, while a sufficiently large dose will lead to the death of the organ, such as the collapse of the gastro-intestinal tract mentioned earlier. If a pregnant woman is exposed to a large dose of radiation during the 8th and 15th week of term, the foetus is likely to suffer an intellectual deficit that is proportional to the dose received while its embryonic nervous system is developing.

Stochastic effects

These effects have a probability of occurring that depends on the radiation dose. In general, only the probability of an effect can be established. The probability of an effect occurring is very low at low doses, and it is assumed to be proportional to the dose with no threshold. It is suspected, but not yet proven, that there may also be a threshold dose for the initiation of stochastic effects as there is for deterministic effects. However, once the effect occurs it progresses all the way irrespective of the initiating radiation dose. This includes the induction of cancer in the exposed person. It should be remembered that there are many causes of cancer in addition to radiation, and once a cancer develops, there is no way of determining what caused that particular cancer in the first place.

Martin and Harbison (see Part 6 Section 8) give some indication of the deterministic and stochastic effects of radiation doses. In general, the risk of a fatal cancer from ionising radiation is about 5 x 10-5 per milliSievert (mSv).

2.3 SOURCES OF RADIATION EXPOSURE

Everyone is exposed to natural radiation from cosmic rays, and radioactive elements in the earth, the atmosphere and our own bodies. The background radiation around the world varies widely with latitude and altitude, and with different underlaying geology. The world average background radiation dose is about 2.5 mSv per year. In South Australia it is about 2 mSv per year. Some people live in places where the background radiation level is ten times greater than for South Australia, without any known ill-effects. The total dose from man-made sources is, on average, about 0.4 mSv and is virtually all due to the medical and dental uses of radiation. A few people, radiation workers, also receive some very small additional radiation dose due to the nature of their work.

2.4 CONTROL OF RADIATION DOSE

The radiation protection program is concerned with the control of occupational exposures and radiation doses.

2.4.1 Dose Limits

Dose limits are like speed limits - they do not necessarily mean there is zero risk for a dose less than the limit. ARPANSA and the SA Ionising Radiation Regulations set down dose limits for occupational exposures. In general, the limits are designed to ensure that the risk of death to a radiation worker through exposure to ionising radiation is no more than the average risk of death in all occupations. This limit is well below the levels at which deterministic effects will occur.

Currently the effective dose limits for radiation workers are 20 mSv per year and for the public 1 mSv per year.

The ARPANSA recommendations on dose limits are included in Part 6.

2.4.3 Dose Constraints

Institutions may establish constraints on the dose received by their workers that are lower than the dose limits specified in the Regulations. It is important to recognise that dose limits do not mean that below these doses there are no biological effects. University policy, as well as the Regulations, state that occupational doses should be **As Low As Reasonably Achievable**, economic and social factors being taken into account (ALARA). With this aim in mind it is expected that no individual at the university will receive an occupational dose greater than 1 mSv a year. This 1 mSv per year is a **dose constraint**. By following normal operating procedures, this is easily achievable by all radiation workers.

2.5 CONCEPTS OF RADIATION PROTECTION

The aim of a radiation protection program in an institution is to reduce the radiation doses, and the risk of receiving a significant radiation dose, to the lowest possible levels that are reasonably achievable for radiation workers and members of the public.

The reduction in dose is achieved by limiting the **exposure** of people to ionising radiation.

Exposures can be controlled by engineering, training and operational procedures and may involve the source (minimum source strength, shielding and containing the source), work practices, and the use of protective clothing and equipment.

The reduction in the risk of receiving a dose is achieved by monitoring radiation doses and by planning so as to reduce the effects of unexpected events during any procedure.

Radiation protection is based on

- **Justification**

  The use of radiation should produce a benefit to the exposed individual or to society to offset any harmful effect that it may cause.

- **Optimisation**

  Exposures to ionising radiation should be kept as low as reasonably achievable (ALARA), taking into account economic and social factors.

- **Dose limits and constraints**

  Exposures of individuals to radiation should be subjected to dose limits and dose constraints by appropriate procedures and verified by monitoring.

2.6 GENERAL PRINCIPLES FOR CONTROLLING RADIATION HAZARDS

2.6.1 As Low As Reasonably Achievable (ALARA)

The primary objective of radiation protection procedures in the University is to ensure that the radiation exposure of radiation workers (those using ionising radiation in the course of their employment or study) and the general public (all others), from both external and internal radiation sources, is kept **A**s **L**ow **A**s **R**easonably **A**chievable **(ALARA principle)**, and well below the dose limits set in the SA Ionising Radiation Regulations.

2.6.2 Exposure to radiation

The use of X-ray equipment or sealed radioactive sources may result in radiation exposure from radiation sources **external** to the body. The handling of unsealed radioactive materials may result in radiation exposure from radioactivity both **external** and **internal** to the body.

Exposure to radiation is

acute if it occurs over a short time, e.g. exposure from a medical X-ray or a radiation accident

or

chronic if it occurs over a longer period of time, e.g. occupational exposure.

2.6.3 Controlling exposure

The measures required to counter external and internal radiation hazards are different.

For external radiation, exposure ceases:

- when one leaves the radiation area,
- the source is removed, or
- the irradiating apparatus is turned off.

External radiation can be measured with relative accuracy and the magnitude of the hazard can be estimated.

For internal radiation, from ingested, absorbed, or inhaled radioactive material, the contaminated person continues to be exposed to radiation even after the external contamination is removed. The resulting radiation dose to the person is considerably more difficult to estimate.

2.6.4 External Exposure

External radiation may come from:

- X-ray generators or sealed radiation sources such as neutron sources, or
- unsealed radionuclides used in a laboratory – with nuclides like P-32 the external radiation hazard can be large.

Exposure to **external radiation** is controlled by:

- **maximising the distance** from the radiation source,
- **minimising the time** of exposure, and
- **shielding** the radiation source.

Distance

Increasing the distance from the source is the most effective and economical means of reducing radiation exposure.

For point sources, the intensity of the radiation varies inversely with the square of the distance from the source. By doubling the distance from the source, the radiation intensity falls to a quarter of the original value.

The variation of the radiation intensity with distance is more complex if the source is large compared with the distances involved (non-point source). The intensity decreases with distance but does not follow a simple law. As a rough guide the inverse square law can be applied if the distance from the source is greater than about 5 times the dimensions of the source.

Distance should be used whenever possible to minimise radiation exposure. Use tongs or other long handled tools rather than fingers for handling radioactive materials. Even short forceps provide a large reduction in the radiation dose from that given to the skin by direct contact.

Time

Decreasing the time of exposure decreases the dose proportionally.

Any new procedure should be practised with non-radioactive materials or as dummy procedures so that the final work with ionising radiation takes the minimum time without error.

Shielding

Shielding placed between the source and the worker absorbs the ionising radiation and therefore reduces the dose rate outside the shielding. It should be used whenever maximum distance and minimum time are not sufficient to reduce exposure to an acceptable level.

General

All three concepts (time, distance and shielding) must be taken together. It is useless to add shielding, or use 2 metre tongs, if these increase the difficulty of working, and consequently increases the time. The dose may be greater than it would be without the shielding or using such long tongs!

2.6.5 Internal exposure

Internal radiation exposure occurs when the body is contaminated internally or externally with a radionuclide through breathing (inhalation), swallowing (ingestion) or contact with the skin (absorption).

Inhalation

Breathing radioactive dust and gas introduces soluble and insoluble air borne radioactive materials not only into the lungs but also into the gastro-intestinal and upper respiratory tracts. Different radionuclides have different long-term biological pathways in the body and present different hazards.

Iodine poses a special problem because of its volatility. Work with materials containing free radioactive iodine requires special precautions.

Ingestion

By drinking contaminated water, eating contaminated food or generally by transferring radioactive material to the mouth, radioactive material may enter the body.

Ingested material is taken up by various organs depending on the chemical nature of the radionuclide, the biochemistry, and the biological pathways involved.

Absorption through the skin

The absorption of radionuclides through intact skin, as well as open wounds, is a hazard as is the retention of radionuclides in and on the skin itself.

Committed Dose

Radioactive material that is inside the body represents a different hazard from external radiation, because in general there is no way to force the elimination of the material from the body. The material will be excreted naturally over time according to the biological half-life of the material. This is in addition to the natural radioactive decay of the material, according to its physical half-life. Someone who has internal radioactive material has a **committed dose** – we can estimate the dose they are committed to receiving over time.

2.6.6 Controlling the internal radiation hazard

Internal radiation exposure is controlled by:

- **limiting the dispersal** of the material so that it cannot be inhaled or ingested, and
- **limiting contact** with the material to avoid absorption.

Control is achieved by good housekeeping methods:

- using the radionuclides in properly designed laboratories,
- confining the handling of the radionuclide preparations in well-defined and separate areas of the laboratory,
- working over spill trays to minimise the spread of any spills,
- wearing appropriate protective clothing,
- following clearly defined procedures and working rules, and
- careful monitoring of workplaces, gloves and protective clothing after use.

2.6.7 Annual Limit on Intake (ALI)

For the internal radiation hazards produced by ingesting, inhaling or absorbing radioactive material, the radiation dose received depends on the nature of the radionuclide, the chemical and biochemical properties of the material and its interaction with the organs of the body.

To help in controlling the internal radiation dose, the **Annual Limit on Intake** (**ALI)** is used. This is the limit on the amount of a radionuclide that can be taken into the body and is dependent on the radionuclide and its biological properties. The ALI may also depend on the physical or chemical form of the radionuclide.

The **ALI**s are designed to ensure that the 20 mSv per year limit on the dose received by a radiation worker is not exceeded.

Derived Limits

The concentrations of radionuclides that can be present in the laboratory air, and the amounts of the radionuclides that can be present as contamination on laboratory surfaces, are limited by **Derived Limits** that are based on the Annual Limit on Intake, ALI. They are:

Derived Air Concentration (DAC) in Becquerel per cubic metre for breathing, and

Derived Limit for Surface Contamination (DLSC) in Becquerel per square cm for contamination.

These are explained more fully in Part 6.

PART 3 – GUIDELINES FOR UNSEALED RADIOACTIVE MATERIAL

3.1 USES OF UNSEALED RADIOACTIVE MATERIAL

Unsealed radioactive materials, whether in solid (powder) or liquid form, may be used in a number of different contexts within this university. Such material may be used in biomedical research, in geo-mineral processing research and in nuclear medicine training. The types of radioactive material and the quantities involved may vary, but the general principles of their safe management and use described in this Part are the same. Students and staff that use such materials outside of the university are reminded that they must still follow the policy and procedures established by this university for their safe use, as a minimum standard.

3.2 HAZARD CLASSIFICATIONS

3.2.1 Radionuclides

The precautions for handling unsealed radioactive substances depend upon:

- the properties of the nuclide (type of radiation, half-life, etc),
- the type of compounds containing the radionuclides and their specific activity,
- their chemical and physical properties, and
- the type of operations being carried out.

Radionuclides are classified into four groups according to their relative hazard. Radionuclides in Group 1 are the most hazardous and those in Group 4 the least. Part 6 contains a table (Table 6.3) of common radioactive nuclides with their classification.

3.2.2 Laboratories

Laboratories in which unsealed radionuclides are used are classified into three types, **A**, **B** and **C**. The type is based on the quantities of radionuclides that can most safely be used in the laboratory.

Type C is the most commonly used laboratory, and is the one where the least quantities of radionuclides are used.

Type B is designed for more hazardous situations involving larger quantities or more hazardous operations such as iodinations.

Part 6 (Tables 6.1 and 6.2) has details of the operations that can be performed with various nuclides in Type B and C laboratories.

3.3 CONTROL OF THE HAZARD

Control of the hazard of unsealed radioactive substances depends on the type of radiation emitted, for example whether the radiation hazard is due to β–particle emission, γ–ray emission or both.

The β-particle emitters normally used in the University can be divided into two groups for hazard assessment: low energy (tritium, carbon-14, and sulphur-35) and high energy (phosphorus-32).

In general, other β-particle emitters will also emit γ-rays which can increase the hazard.

Nuclides which are α emitters can be very hazardous, and are classified as equivalent in hazard as tritium. Natural uranium and thorium are the only unsealed α-particle emitters used in the University.

Specific information for handling common radioactive nuclides can be found below in Section 6.

3.3.1 Shielding and Distance

The dose constraint of 1 mSv per year applied by the University to radiation workers is equivalent to about 0.5 μSv per hour for an exposure of 40 hours per week and 50 weeks per year. In practice no one is exposed for this time, and the dose constraint will be met if workers are not normally exposed to radiation fields which will deliver more than 1 μSv per hour to the body. A radiation field of 1 μGy per hour will deliver approximately 1 μSv per hour to the body for the radionuclides used in the University, which emit only β and γ radiations.

Shielding and distance should be used to reduce radiation fields to a norm of 1 μGy per hour.

The shielding reduces the external dose to workers by absorbing the energy of the ionising radiation in the shielding material. The type and thickness of the shielding required is dependent on the kind of radiation emitted by the nuclide.

The intensity of the radiation field should be checked whenever a new procedure or batch of radioactive material is used and, if necessary, appropriate shielding and distance used to reduce the dose rate. For most work in the University, the external radiation hazard is very small and the risk of ingestion is the main concern, but the external radiation field may be important when handling large quantities of radioactive material.

3.3.2 Gamma-Ray Emitters

The absorption of gamma-radiation depends on the electron density of the material, so that dense materials like lead are the best absorbers. Other substances can be used, but the thickness required to reduce the dose will be larger.

The thickness of lead required to reduce the radiation field by a factor of 10 is included in the data for common radionuclides in Table 6.3, Section 6.

In general, the combination of distance (the trunk will normally be 50cm or more from a source on a laboratory bench) and minor shielding will be sufficient for a few MBquerel of unsealed gamma-ray emitters.

3.3.3 Beta-Particle Emitters

Many radionuclides used in biological laboratories are beta-particle emitters – tritium, carbon-14, sulfur-35 and phosphorus-32 or phosphorus-33. The beta-particles are relatively easily absorbed in any material, but X-rays called **bremsstrahlung** are produced when the beta-particles (electrons) are slowed down in the shielding material.

The bremsstrahlung from low energy beta-particle emitting radionuclides such as H-3 and C-14, are not particularly hazardous but must be considered when using more energetic beta-particle emitting radionuclides, such as P-32.

In general, a few mm of glass or Perspex are sufficient to absorb all low energy beta-particles; for P-32 10-20 mm of Perspex is sufficient, but lead may also be needed after the Perspex to absorb the bremsstrahlung.

3.4 MONITORING

Two types of monitoring are used in laboratories with unsealed radioactive materials:

- measurement of the **external radiation field** (which should be less than 1 μSv per hour at the body), and
- measurement of the **contamination** of benches, equipment and workers by the radioactive material (normally less than 100 cpm/100 cm^2)

Monitoring of **external** radiation fields is not necessary in laboratories where only H-3, C-14, and S-35 are used.

Monitoring for **contamination** should be carried out routinely to ensure that surface contamination levels are lower than the limits specified in Table 6.3, and especially to check that hands have not been contaminated by the work.

Monitoring should be carried out with a survey meter suitable for the type of radiation being used. In some cases, contamination will have to be checked using a **wipe test**.

Each laboratory and work area must have ready access to a contamination detector that can be used to monitor surface contamination and spills.

3.4.1 Monitoring Techniques

External radiation fields

Always measure the external field from a new supply of radionuclide before opening it. Accidents have occurred due to incorrectly labelled or packaged material!

- Measure the radiation field close to the source and also at the distances where you will be using the material (hands, body).
- Estimate your body dose from the measured dose rate and your expected working time. This should be less than 1 μSv per hour (ie 1 mSv in a year). If it is more than this consult your supervisor and Department Radiation Safety officer.
- Monitors should be checked before use in a low background area and with a known source to verify their proper operation.
- If the radiation field is much greater than expected do not continue the survey. Back off, close off the area and seek help from your supervisor and Department Radiation Safety officer.

Contamination

The amount of radioactive material on a surface (contamination) is generally expressed in terms of counts per minute or second. Contamination limits (Table 6.3) are expressed in Becquerel per square cm. The link between the measurement in counts per second and the activity in Becquerel (disintegrations per second) is complicated by the sensitivity of the detector for the radiation and the geometrical detection efficiency.

For routine surveys it is normally sufficient to check that there is no gross contamination, and a rough efficiency factor for the counter can be estimated by measuring a known source of the radionuclide. Efficiencies will in general be between 0.5% and 5%. The detection of X and γ-ray emitters is generally more efficient using scintillation detectors rather than Geiger-Muller (G-M) counters. For P-32, a counting efficiency of about 10% or more is normally obtained with a G-M counter.

For very low energy beta-particle emitters, such as H-3, the wipe test is the only satisfactory check for contamination.

Objectives of Surface Monitoring

The main objectives of monitoring for surface contamination are:

- to assist in preventing the spread of contamination,
- to detect failures of containment or operating procedures, and
- to restrict surface contamination to levels at which a general standard of good housekeeping is sufficient to keep exposures as low as reasonably achievable and ingestion below the ALI.

Area, Equipment and Personal Surveys

Always measure the contamination levels after you have finished work – check trays, work benches, equipment and anything that may have become contaminated.

Always check your gloves before removing them (with P-32 a contaminated glove may give a large radiation dose to the skin).

The monitor should be held over an area for a few seconds so that it has time to respond to count rates which may be as low as a few counts per second.

The probe should be held as close as practical to the surface being monitored to increase the efficiency and to best define the contaminated area. But avoid contaminating the probe by letting it touch the contaminated surface. Cover the probe with a thin plastic cover that can be easily replaced if it becomes contaminated.

Monitors should be checked before use in a low background area to verify their proper operation.

Wipe Tests

Gloves should always be worn when carrying out a wipe test!

A wipe or smear sample can be taken from the surface using a tissue or filter paper (wet or dry).

Wipe the surface gently with the paper and then place the paper wipe in liquid scintillant in a scintillation vial for counting with the scintillation counter. The detection efficiency is good and this is the best method for checking for surface contamination from low energy emitters.

A wipe test may remove any fraction up to 100% of the contamination present on the surface. Generally a **removal factor of 10%** is assumed if no other information is available.

Wetting the wipe with water or a solvent is likely to increase the amount of contamination removed.

An area 10 cm x 10 cm should be wiped if the results need to be compared with the contamination limits.

3.5 GENERAL RULES FOR UNSEALED RADIOACTIVE MATERIAL

Radiation protection practices for the safe handling of unsealed radioactive substances can be complex, but they can be simplified to **ten basic rules.**

3.5.1 Familiarity with Procedures

- In all operations, the degree of danger is related to the user's lack of knowledge and experience. Before handling radionuclides ensure that you understand the nature of the radiation hazard and are familiar with all the procedures necessary for the particular job, including procedures to handle spills.

- New workers must be trained, and new procedures practised, with non-radioactive materials.

3.5.2 Working Rules for Handling Radionuclides

- A set of working rules or Standard Operating Procedures must be posted in every laboratory where unsealed radioactive substances are handled.

- Always work carefully and tidily. Avoid contaminating yourself and others.

3.5.3 Distance

- Distance should be used whenever possible to minimise radiation exposure as it is the most effective means of radiation protection.

3.5.4 Time

- Radiation exposure can be reduced by minimising the time spent performing operations.

- Plan ahead and if necessary do a dummy run without using any radioactive material to check your procedures.

- Remember that the shorter the time, the smaller the dose.

3.5.5 Shielding

- Use the correct type of shielding for the type of radiation you are using. β-particles may be stopped by Perspex, but be aware that **bremsstrahlung** (X-rays) are produced by high energy β-particles.

- Remember in a shield use Perspex first, then lead. Use an appropriate thickness of lead for X and γ-ray emitters (Table 6.3).

3.5.6 Protective Clothing

- Protective clothing must be worn to reduce the risk of contamination.
- Eye protection must be worn at all times when working with radioactive material. Eyes are especially sensitive to radiation and local doses from contamination can be very high.
- Laboratory coats or gowns with long sleeves that can be tightened at the wrist are desirable, particularly when handling high specific activity or volatile radionuclides. The minimum amount of unprotected skin should be left exposed. In most cases, the wrists are forgotten and are left unprotected.
- Gloves must be worn at all times as hands easily become contaminated and increase the risk of the spread and ingestion of radioactivity. The radioactive material **may** be able to penetrate skin and two pairs of gloves may need to be worn, such as with high concentrations of elemental iodine, which can penetrate some rubber gloves.
- During procedures where gloves frequently need to be changed to prevent the spread of contamination, the outer glove is changed and the inner glove minimises the risk of skin contamination.
- Gloves should be carefully removed by turning inside out, avoiding contact between the skin and the outside surface of the gloves. They must always be assumed to be contaminated and be discarded into the radioactive waste bin.

3.5.7 Containment

- The minimum limit of containment is that work must be confined to a registered laboratory.
- People who are not radiation workers must be discouraged from using a registered laboratory for social visits.
- When working with radioactive materials the spread of radioactive contamination is further reduced by working within a contained work area or fume cupboard.
- Always keep active and inactive work areas separate.
- Manipulations should be performed over trays to contain the spread of accidentally spilled material.
- If aerosols are likely to be produced, or if volatile radioactive materials such as iodine compounds which may be oxidized, or tritiated water are being used, procedures must be carried out in a fume cupboard.

3.5.8 Monitoring the work area and yourself

- A contamination monitor must be available for area and personal contamination checking and to detect spills.
- The monitor must have the correct energy response/sensitivity for the radionuclide being monitored.
- Work areas must be regularly monitored for contamination.
- For routine monitoring purposes, contamination should be averaged over an area of 50 to 100 cm^2. If local hot spots are detected, the monitoring should be done over a small area.
- The surface contamination of surfaces must be kept below the limits listed in Table 6.3.
- Remember that contamination is most common on the hands and can usually be removed by washing if detected early enough.

3.5.9 Waste disposal

Overall management of radioactive waste is the responsibility of the University through the University Radiation Safety Officer and the Department Radiation Safety Officers.

- Always use the minimum quantity of any radioactive material possible.
- Minimise the accumulation of radioactive waste in your laboratory and store it appropriately.
- Follow the local rules for handling waste displayed in the laboratory.

3.5.10 Spills and contamination

- A summary of the emergency procedures must be displayed in the laboratory.
- In the event of a spill in which material escapes from the containment (tray, tube, beaker, etc) follow the emergency procedures detailed in the Laboratory Rules.
- Warn people in the vicinity of the spill.
- If the spill is large enough to qualify as a “Radiation Incident” follow the procedures in Part 6.
- treat contaminated personnel first, then proceed to decontaminate the area or equipment.

3.6 RECORD KEEPING FOR RADIONUCLIDES

One way to control the hazard from radioactive materials is to keep records of the amounts and locations of the material. Record keeping of this kind is demanded by the SA Ionising Radiation Regulations.

Each laboratory must keep a **register** that contains:

- the radionuclides contained in the laboratory,
- the activity,
- the date to which the activity refers,
- the name of the person who has care of the material,
- the date when the substance entered the laboratory,
- material leaving the laboratory (normally as waste) must be recorded, and
- the quantities sent to the sewer (through the Radioactive Waste Management Plan) must be recorded.

The register may be kept electronically or in a notebook. For material leaving the laboratory as waste, it is normally sufficient to estimate the quantities involved from the amounts used in the experimental program.

3.7 STORAGE OF RADIONUCLIDES

The rules for the storage of stock materials, waste and material being used in the laboratory are basically the same. The regulations only provide an exemption from labelling where the container is too small to allow labelling.

- All radioactive materials must be labelled as “Radioactive”, with the trefoil symbol, the quantity and type of radioactive material, and the date.
- Radioactive materials must be stored with reasonable precautions against unauthorised access (locked room when unattended).
- Always store radiochemicals according to directions given by the supplier in specification sheets.
- Where possible radionuclides should be stored in a double container, with the outer one of plastic in case of breakage.
- Radionuclides must be appropriately shielded with lead, or Perspex and lead if bremsstrahlung are present.
- Storage areas (including refrigerators) must be marked with the appropriate **radiation signs**.
- **Never** leave radionuclides in unsealed containers in cold rooms or refrigerators.
- Make sure that containers that will be frozen are not full and cannot break on freezing. Use an outer container as a precaution.

3.8 INFORMATION ON PARTICULAR RADIONUCLIDES

3.8.1 Low Energy Beta-Particle Emitters: tritium, carbon-14, and sulfur-35

The energies of the beta-particles from these radionuclides are so low that the **external** radiation hazard is negligible.

External contamination is not a hazard in itself, but must be kept to a minimum as it can lead to ingestion and internal contamination, and can also interfere with experimental results.

All three nuclides have the potential for incorporation into biologically important molecules, such as DNA and proteins.

Care should be exercised when using these radionuclides despite their apparent low radiation risk.

S-35 labelled compounds (especially methionine) may be easily volatilised at moderate temperatures. Heating S-35 materials should always be performed in a fumehood.

3.8.2 Phosphorus-32

Phosphorus-32 is the highest energy β-particle emitting radionuclide commonly encountered, and requires special care. The maximum range of P-32 β-particles in air and soft tissue is about 7 mm. The bremsstrahlung radiation (X-rays) produced when the P-32 β-particles are absorbed in the source, shielding or container can be a significant external hazard.

For shielding P-32 β–particles, 10 mm of Perspex is sufficient. The Perspex or glass container should be surrounded by about 3 mm of lead to absorb the more penetrating bremsstrahlung.

The dose rates from typical quantities of P-32 can be very high, reaching hundreds or thousands of μSv per minute at the wall of a vial containing P-32. In the same way, concentrated solutions of P-32 in Eppendorf tubes can give enormous dose rates at the surface of the tubes – as much as 1000 μSv per minute at the base of a tube containing 1 MBq P-32 in 0.1 ml!

Handling tubes containing P-32 directly can deliver doses of tens of μSv per second to the skin. Handle Epindorf tubes in Perspex shields and use forceps if they are removed from the shielding. The dose rate will fall by a factor of ten thousand by moving your fingers from a distance of 1mm to 10 cm with forceps.

These very high doses can make skin contamination with concentrated P-32 solutions a serious hazard. Contamination of the skin by 1 MBq of P-32 may lead to skin doses of 1000 μSv per second!

The hazard is increased if eyes are contaminated because of the increased sensitivity to radiation damage.

Eye protection MUST be worn at all times when handling P-32 solutions. A splash could lead to serious damage in a short time.

It is desirable to work with P-32 behind a small Perspex shield - this not only acts as a β–particle shield but also reduces the chance of splashing causing contamination.

3.8.3 Iodine-125

The energy of I-125 γ-rays is relatively low (0.035 MeV) and direct shielding may only be needed for quantities of more than 50 – 100 MBq.

The main hazard with radio-iodine is inhalation; the hazard is increased because it is selectively taken up by the thyroid.

Iodine compounds can easily generate volatile elemental iodine, which may then be breathed in. Great care must be taken to reduce the risk of inhalation of elemental iodine.

Radioactive iodine bound to the carriers used in radioimmunoassays is less hazardous than iodine or iodide ions. Except in the small quantities used in some RIA kits (<400 kBq), radioactive iodine **should** (< 40 MBq) and **must** (>40MBq), only be used in a Type B laboratory.

- All operations with radioactive iodine must be performed in a properly operating fume-cupboard and, if possible, the fan should be left running continuously.
- Containers should be opened for as short a time as possible.
- It is advisable to wear two pairs, or use a pair of polythene gloves over the rubber gloves, as some iodine compounds can penetrate surgical rubber gloves.
- To reduce the formation of volatile elemental iodine, solutions containing iodide ions must not become acidic or be stored frozen. Compounds of radioactive iodine may generate free iodine by radiolytic decomposition.
- A solution of sodium thiosulfate must be available when handling radioactive iodine compounds. Poured on a spill this makes sure the iodine is in the reduced form for clean up.
- Contaminated wastes must be sealed before being sent for storage or disposal.
- Materials which may contain radioactive iodine must never be treated with oxidisers, such as bleach, as this releases free iodine.
- The low γ-ray energy of I-125 and the volatility of iodine make contamination surveys difficult.

PART 4 - GUIDELINES FOR USING X-RAY GENERATING APPARATUS

4.1 USES OF X-RAY GENERATING APPARATUS

There are two main types of X-ray generating apparatus: X-ray machines used for both medical and non-medical (non-destructive testing) imaging purposes, and X-ray analysis apparatus, used for laboratory chemical and structural analysis. Students and staff that use such equipment outside of the university are reminded that they must still follow the policy and procedures established by this university for their safe use, as a minimum standard.

4.2 IMAGING X-RAY MACHINES

The Standard Operating Procedures and special precautions necessary when working with imaging X-ray machines are:

- Only those people licensed to operate an X-ray machine under Regulation 31 of the Radiation Protection and Control Act, 1982, can operate the machine and for the purposes stated in their licence conditions which appear on the back of the licences.
- Other personnel may assist examinations, but only under the direct instructions of a licensed operator.
- All personnel not essential for the examination must leave the room during the operation of the X-ray machine.
- The operator and other personnel essential to the examination should take appropriate radiation protection precautions during all examinations. That is, for mobile X-ray machines be more than 2 metres from the X-ray tube and patient or object being examined, or wear a lead rubber apron. For fixed X-ray machines, the operator must stand behind the protective screen whenever practicable.
- Appropriate warning signage must be in place for both mobile and fixed installations, with ‘X-ray ON’ lights visible when the X-ray machine is energized.
- Interlocks on the X-ray machine and doors must never be overridden.
- Work must not be done on the X-ray machines while they are energized.
- The primary radiation beam should always be collimated to include only the area of interest. This must always be within the size of the film. The primary beam must not be directed at the operator or assistant.
- No part of the operator’s or assistant’s body should ever be in the primary beam. The primary X-ray field is clearly defined in X-ray machines by means of a light beam. Scattered radiation is the major radiation hazard in this situation. If it is necessary for any part of the operator’s or assistant’s body to be near the primary beam, then lead shields must be used, including wearing lead rubber aprons and/or gloves when necessary, to protect the operator and/or assistant from scattered radiation.
- Exposure settings (kVp and mAs) must always be consistent with obtaining a diagnostically adequate radiograph. It should never be necessary to repeat an exposure to obtain a better quality image. Where ever possible, use an appropriate film/screen combination.
- Gonad shielding should always be used on patients of reproductive age or younger, whenever it does not interfere with the examination.
- All female patients of reproductive age should be asked if they are pregnant. If there is any possibility that they are pregnant, then the radiographic examination should only proceed if the benefit to be obtained by the patient is judged to exceed the risk involved, using appropriate protective shielding.

- The radiographic examination being carried out must be in accordance with the licence conditions of the operator.
- All medical radiographic examinations should only be carried out if they are authorised in writing by a medical practitioner. In the case of an emergency, where written authorisation cannot be given before the examination, the oral authorisation must be followed up within 24 hours by a written confirmation of the authorisation. Written authorisation does not apply if the medical practitioner takes the radiographs himself/herself. However, in that case the medical practitioner must have a licence to take radiographs.
- The operator must report any malfunction or defect in the X-ray machine to their supervisor.
- All personnel must wear their personal monitoring device (TLD badge) at all times when using an X-ray machine, or when it is essential for them to be present in the X-ray room while a radiographic examination is being carried out.

4.3 X-RAY ANALYSIS APPARATUS

Standard Operating Procedures must be established and followed by all users of X-ray Analysis apparatus. The general term X-ray analysis apparatus applies to all types of X-ray Diffraction and X-ray Fluorescence apparatus. Other laboratory equipment, such as electron microscopes, emit X-radiation incidental to their main function but still must be operated safely.

4.3.1 Types of X-Ray Analysis Apparatus

There are three types of X-ray analysis apparatus described in the Regulations; (i) enclosed, (ii) partly enclosed, and (iii) open-beam. In general, X-ray fluorescence equipment is of the enclosed type. X-ray diffraction equipment may be fully enclosed, but is frequently partly enclosed, or it may be open-beam.

(i) *Enclosed* (Regulation 68(3))

This is the safest type of X-ray equipment. The primary X-ray beam is completely enclosed inside a shielded enclosure that completely surrounds and prevents access to the beam and prevents radiation leakage during normal operation of the equipment. The enclosure must be interlocked so that the enclosure cannot be removed unless the shutter on the primary beam is closed. Opening the shielded enclosure must de-energize the X-ray tube or close the primary beam shutter.

(ii) *Partly Enclosed* (Regulation 68(4))

This is less safe than enclosed equipment, but safer than open-beam equipment. Prevents access to the beam, but allows some radiation leakage to occur during normal operation of the equipment. The enclosure must be interlocked so that removing the enclosure de-energizes the X-ray tube or closes the primary beam shutter or prevents the primary beam shutter opening.

(iii) *Open-Beam* (Regulation 68(5))

This is the least safe type of X-ray analysis equipment. There is no system of interlocked shielding, and users must take the greatest care when operating this equipment. The regulatory constraint is the absorbed dose rate at any point on the surface of a volume defined by the plan of the equipment and its vertical projection from the floor to the maximum height of the equipment. Under all operating conditions, this dose rate must not exceed 25 μGy per hour. Shielding used to reach this dose rate must be securely attached to the equipment or the room.

4.3.2 General Requirements for X-Ray Tubes

The X-ray tubes in X-ray analysis equipment must be enclosed in a tube housing that is equipped with interlocked shutters and be adequately shielded in its own right. It should not normally be possible to operate the X-ray tube outside of its tube housing.

4.3.3 General Requirements For X-Ray Analysis Apparatus

The Regulations cover the requirements for X-ray analysis units in considerable detail. The details governing warning lights and signs for use with X-ray equipment are set out in the Regulations and are normally checked when the X-ray equipment is registered.

Lights

These must be red or amber and fail-safe.

A lighted sign must indicate that the X-ray machine is operating.

All shutters must be linked to a light that is lit when the shutter is open and clearly indicates that the shutter is open.

Signs

All X-ray apparatus must have a sign "Radiation Produced when Energized", usually near the control panel.

The door of the room containing either closed or partly closed X-ray equipment must have a sign "Caution - Radiation Area" and the radiation symbol.

Open-beam equipment must have sufficient number of signs "Danger – Open-Beam X-ray Analysis Unit" and the radiation symbol, to be visible from all normal access routes to the X-ray analysis equipment.

It is desirable to mark out on the floor the limit of the open-beam unit plan using black and yellow hazard tape.

4.3.4 Hazard: Primary and scattered beams

The hazard from X-ray generators in the University is much greater than that from unsealed radioactive sources. X-ray apparatus must always be treated as a potentially very serious hazard and interlocks must be working and operating rules must be followed whenever the apparatus is in use.

Primary Beam

In X-ray analysis equipment, the primary beam is normally highly collimated and may only be a millimetre in cross-section. The resulting high intensity of the primary beam requires all users to be constantly on guard against placing any part of the body in the beam. The collimation means that the inverse square law does not apply, and dose rates may fall only slightly over distances of a metre or more.

The hazard is worst with open beam units.

X-ray tubes can produce dose rates as high as **100 - 200 mGy per minute**. At these dose rates severe deterministic effects can be produced very quickly. The eyes can be permanently damaged within a few seconds (corneal clouding and blindness), the skin can receive severe radiation burns and the bones of fingers or skull can be damaged.

These effects can take several days or weeks to become obvious and **there is no immediate warning that the dose has been absorbed.** The use of personal dosimeters is limited to measuring the amount of scattered radiation absorbed, because with the small beam size it is improbable that if a worker is exposed to the primary beam this beam will strike the dosimeter.

Scattered Beam

The primary beam is easily scattered by any material in its path, from either equipment or shielding. The high intensity of the primary beam means that the scattered radiation may be a very significant hazard. Enclosed equipment should produce no scattered radiation outside the enclosure. However, in partially enclosed beam equipment, the partial shielding can be a significant source of scattered radiation, and goniometers are a major scattering source in open-beam equipment.

4.3.5 Control of the Hazard

Engineering (shielding, interlocks, locked rooms) and operational rules (licences, signs, training, monitoring) are the only ways to control the hazard.

Engineering

The general engineering controls are included in the Regulations for registration of the equipment.

If the engineering controls must be over-ridden (for example, for maintenance), then every precaution must be taken to avoid any possibility of exposure to the primary beam and the area must be monitored for the scattered beam. If interlocks are temporarily by-passed, this must be shown on a notice attached to the control panel.

Rooms containing X-ray equipment must always be kept locked, even when the equipment is not being used, to prevent unauthorised use.

Operational rules

General working rules for X-ray analysis equipment are included in Part 6.

Monitoring

Monitoring for scattered radiation must be part of the routine operations of an X-ray analysis unit. The Regulations require monitoring once every six months but this must be supplemented if changes are made to the physical arrangements of partly enclosed and open-beam units.

Records must be kept of the monitoring program.

Mechanical and electrical checks

The system of warning lights and interlocks must be checked at no longer than six-monthly intervals.

The dose rate of the radiation field around the unit should be checked at the same time.

The results of the checks must be recorded.

Similar checks must be made whenever the overall experimental arrangements are changed.

PART 5 - GUIDELINES FOR SEALED RADIOACTIVE MATERIAL

5.1 USES OF SEALED RADIOACTIVE MATERIAL

This Part applies to radioactive material that is sealed within a capsule (a sealed source). Sealed sources include low activity calibration sources, irradiators and neutron sources, and may be fixed or portable (neutron soil moisture meters and soil density gauges). They are also used in medicine in Brachytherapy treatments and may still be found in some old Teletherapy machines. Students will encounter them in their Radiotherapy training.

Some sealed sources are highly active and emit potentially dangerous levels of radiation; considerable care must be taken with such sources.

With all sources it is important to keep track of their location and who is currently responsible for them.

Students and staff that use such materials outside of the university are reminded that they must still follow the policy and procedures established by this university for their safe use, as a minimum standard.

5.2 TYPES OF SEALED SOURCES

Sealed sources can be divided into:

- those that are housed and used in a shielded container in a fixed location (such as irradiators),
- those that are housed and used in a portable shielded container in which the source is semi-permanently fixed (such as soil moisture meters), and
- those that are stored in a shielded container but which are easily removed for use (calibration and demonstration sources).

5.3 HAZARD

5.3.1 External radiation

In general, the hazard from sealed sources is the external radiation. With fixed sources sufficient shielding can be provided to reduce the external radiation dose rate to acceptable levels in normal circumstances. With portable sources there may be a conflict between the thickness of the shielding and the portability. Calibration and demonstration sources are weaker, but the small size and portability can aggravate the external radiation hazard so that misplaced, lost or stolen sources may be a serious potential hazard.

5.3.2 Contamination

The major hazard from sealed sources is the external radiation field, but if the sealed capsule is corroded or broken then the radioactive material may leak out. The activity and the specific activity of the radionuclides in sealed sources are usually much higher than the activities of unsealed radioactive materials used in laboratories, so that a leak from a broken source will be a major contamination hazard.

5.4 MAINTENANCE AND CHECKING OF SEALED SOURCES

Because of their relatively long life, and their inclusion in equipment or shielded housings, sealed sources may be included in plans for alterations, repairs or maintenance. A number of serious radiation accidents have occurred due to sealed sources being machined or opened, and the health and contamination consequences can be extremely serious.

5.4.1 No Repairs

Repairs, maintenance and modifications to sealed sources must never be carried out unless the University Radiation Safety Officer, and the Radiation Protection Division, EPA, have given explicit written permission for the work.

Actions such as wipe testing of sealed radioactive sources must only be carried out with the approval of the University or Department Radiation Safety Officer.

5.4.2 Wipe Tests

The integrity of the encapsulation of sealed sources must be checked regularly. This can be done by a wipe test of the source, or of the region of the source container most likely to be contaminated if the source is leaking. A wipe test is done by wiping a filter paper or heavy-duty tissue across the area or source, and then performing a radiation count of the wipe paper or tissue. Care must be taken that carrying out a wipe test does not expose anyone to radiation from the source.

If the activity is above background the source must be taken out of service, and the University and Department Radiation Safety Officers informed.

Most sealed sources should be wipe-tested every six months and the test recorded in the source logbook.

Sources that are difficult to wipe test because of the construction or housing should have the shielding wipe tested regularly.

5.5 GENERAL REQUIREMENTS FOR SEALED SOURCES

The Ionising Radiation Regulations cover the requirements for sealed sources in considerable detail.

The Radiation Protection Division, EPA, checks many details, such as the source design, when the source is initially registered, but other requirements are the responsibility of the University and the licensed users.

5.5.1 The Register

The University must keep a register of its sealed sources. Full details such as the manufacturer, the radionuclide and activity, and its storage location must be included. The details are those that are required for the University to be able to register the source. It is anticipated that in the near future, evidence of a physical audit of the source will be required at the time of renewal of the source registration.

Each School/Institute, in which a sealed source is used, must keep a local source register with the following details:

- the identifying label of the source,
- the radionuclide, its activity and the date of measurement, and
- the normal location of the source (storage place).

A licensed person must sign out the source when it is removed from the store and record its temporary location, the time and date. On its return it must be signed in with the time and date.

If sources are used for undergraduate teaching in different laboratories, under the supervision of different staff members, one person must be nominated to be responsible for maintaining the register of the day-to-day movements of the sources.

Where sealed sources, such as neutron moisture meters, are moved as part of their normal use, eg taken off campus, and used in the field, a register of location must be maintained as required by Regulation 150.

It is desirable to keep a record of wipe tests in the register.

5.5.2 Signs

All sealed sources must have a sign with "Radioactive", the radiation symbol, and the radionuclide and its activity. This sign should be attached to the source where it is easily seen and, if the source is portable, any carrying case should have the same sign.

The door of the room containing the sealed source must have a sign with "Caution - Radiation Area", the radiation symbol, and the name and telephone number of the contact person in emergencies.

5.6 CONTROL OF THE HAZARD

Engineering (shielding, interlocks, locked rooms), operational rules (licences, signs, training, monitoring) and maintenance (wipe tests) are the only ways to control the hazards of sealed sources.

5.6.1 Engineering

The general engineering controls are included in the Regulations for registration of the equipment.

A room containing a sealed source should always be kept locked to prevent unauthorised use. During use a licensed person must remain in the room if it is unlocked.

5.6.2 Operational Rules

General working rules for sealed sources are included in Part 6. Standard Operating Procedures (such as those for the use of neutron moisture meters) must be established for each type of sealed source and strictly adhered to.

5.6.3 Monitoring

Monitoring for scattered radiation must be part of the regular checking of sealed sources, such as the fixed neutron source and portable neutron moisture meters. Neutron sources should be regularly checked for the gamma radiation component. If this is unexpectedly high, arrangements should be made for the neutron dose rate to be measured.

Records must be kept of the monitoring program.

5.6.4 Maintenance

A program of routinely checking that the source mechanics are working correctly is important. Mechanical failure can make it impossible for the source to return to its shielded container or cause the source to become loose during transport.

Do not continue to attempt to use a source that has any difficulties in its operation. Report all such operational problems immediately to the Department Radiation Safety Officer.

5.7 STORAGE

In general, sealed sources must be stored:

- so the dose rate in areas accessible to members of the public is as low as reasonably achievable, and is not more than 25 µGy/h,
- in a room which is locked unless a licensed person is present, and
- the room key should only be available to the people licensed to operate the source.

In order to reduce the possibility of misuse, small sources should be stored inside an appropriately shielded and locked cabinet.

5.8 TRANSPORT

The Code of Practice for the Safe Transport of Radioactive Material (Commonwealth of Australia, 2001) controls the transport of all radioactive materials. The Code has been incorporated into the SA Radiation Protection and Control (Transport of Radioactive Substances) Regulations 2003. In practice, it is sealed sources such as neutron moisture meters that are regularly moved off the campus area. The general radiation hazard from these sources could be considerably increased if there is a road accident and emergency services and other aid workers are not aware that a radiation hazard exists.

Only a licensed person can transport sealed sources. The most commonly transported sources are neutron moisture meters and soil density gauges. These must be carried in their carry cases, placed in the vehicle and securely restrained.

The vehicle must be fitted with three radiation warning signs (rear and two sides).

A Consignment Note in the form required by the Code of Practice must be carried in the vehicle with the source. The names and telephone number of the University Radiation Safety Officer and the Emergency Number for the Radiation Protection Division must also be carried.

Details of the requirements for the transport of radioactive materials are contained in Part 6.

5.9 DISPOSAL

There is as yet no national storage facility for unused sealed sources. Sources that are no longer needed must continue to be registered and stored by the University. The long-term storage of sealed sources is under the supervision of the University Radiation Safety Officer.

PART 6 - REFERENCE INFORMATION FOR RADIATION PROTECTION

6.1 UNITS ASSOCIATED WITH RADIATION PROTECTION

The deposition of the energy from the radiation causes the damage to biological material and the associated risk. The fundamental definitions and units needed in radiation protection are therefore connected with energy deposition.

6.1.1 Dose

Absorbed Dose

The amount of energy absorbed per unit mass by any medium from any type of ionising radiation is the absorbed dose. It is often just called the dose.

The unit is the **Gray (Gy), where 1 Gray = 1 Joule per kg.**

One Gray is a large dose and prefixes are commonly used, such as:

milliGray, 1 mGy = 10^{-3} Gy, and microGray, 1 μGy = 10^{-6}.

Dose Rate

This is the rate at which a dose is delivered, such as in μGy per hour (radiation work) or mGy per minute (diagnostic X-ray).

The dose rate is typically the quantity measured when a radiation field is monitored. The total dose likely to be received by someone in that field is then estimated by multiplying the dose rate by the exposure time.

Equivalent Dose

Different kinds of radiation produce different biological effects for the same absorbed dose. For instance, neutrons cause 5 to 20 times as much damage per Gy as 1 MeV gamma-radiation. To allow for this in estimating the hazard of different types of radiation, we use the equivalent dose, which is the absorbed dose (Gy) multiplied by a weighting factor for the type of radiation involved.

Equivalent dose is a measure of the **biological damage** caused by radiation in human tissues, and its unit is the **Sievert (Sv).**

Equivalent Dose (in Sv) = Absorbed Dose (in Gy) x Radiation Weighting Factor.

The equivalent dose is the most important general quantity for radiation protection purposes.

Absorbed dose and equivalent dose are numerically the same for the most common radiations (X and γ-rays, and β-particles). For this reason, equivalent dose is also often just referred to as “the dose”.

Radiation Weighting Factor w_R

This depends on the radiation, and is 1 for β-particles and γ and X-rays, and larger for neutrons (5 to 20 depending on the energy) and α-particles (20).

If a tissue or organ is irradiated by several types of radiation, the equivalent dose to that tissue or organ is the sum of the absorbed doses received by each type of radiation multiplied by their respective radiation weighting factors.

Effective Dose

Tissues and organs in the body differ in their sensitivity to radiation. The skin and liver are much less sensitive than the gonads or bone marrow. **Tissue weighting factors, w_T,** are used to indicate the relative sensitivity of the tissue to the radiation. The sum of the Tissue Weighting Factors for all of the organs in the body is equal to one. The effective dose is also measured in Sieverts.

Effective Dose (in Sv) = Equivalent Dose (in Sv) x Tissue Weighting Factor.

The effective dose is used as an indicator of the effects of radiation on the body as a whole when different body organs are exposed to different levels of equivalent dose.

The effective dose is also measured in Sieverts, and is the sum of the equivalent doses to the irradiated organs multiplied by their respective tissue weighting factors.

6.1.2 Activity

This is a measure of the number of disintegrations occurring per unit time in the sample, dN/dt, and is proportional to the number of radioactive atoms present in that sample, N.

Activity, $A = dN/dt = \lambda N$, where λ is the decay constant for that radionuclide.

The unit is the **Becquerel (Bq),** where 1 Bq = 1 disintegration per second.

For general purposes, the rate at which a radioactive material is disintegrating (decaying) is the most useful quantity. Because the decay rate is directly proportional to the number of atoms of the radionuclide, the activity is a measure of the quantity of radioactive material. It is important in designing experiments and in estimating the hazard from the radiation produced by the decay.

As 1 Bq is an exceedingly small activity, we virtually always use kiloBecquerel (kBq), MegaBecquerel (MBq) or GigaBecquerel (GBq). Some sealed sources may even be in the Terabecquerel (TBq) range.

6.1.3 Half-life

Radioactive Half-life

The activity of all radioactive materials decreases exponentially with time at a rate determined by its own characteristic decay constant, λ. A more useful way of describing the rate of decay of a particular radionuclide is in terms of its Half-Life, τ. This is the time that it takes for the original activity of a sample to decrease to 50% of its original value. It can be shown that the product, $\tau\lambda = \ln 2$. Values of half-live can be, for different radionuclides, shorter than a microsecond or longer than a billion years.

Biological Half-life

The way in which a drug introduced into the body is eliminated from the body, by excretion, exhalation, perspiration, etc, is roughly exponential in time. Consequently, it is possible to define a biological half-life for that particular drug, τ_b. It is the time that it takes for the original amount of the drug introduced in the body to decrease to 50% of its original amount.

Effective Half-life

If the introduced drug also happens to be radioactive, then we can define an effective half-life of the radioactive drug in the body that takes into account both its radioactive and biological half-lives. The Effective half-life, τ_e, is given by: $1/\tau_e = 1/\tau + 1/\tau_b$. For example, if the radioactive and biological half-lives were 6 and 12 hours, respectively, then the effective half-life would be 4 hours.

6.1.4 Old Units

These are still common in the USA, and are therefore still used in many books and laboratory protocols.

Absorbed dose:

Radiation Absorbed Dose. 1 rad = 10 mGy

Equivalent and effective dose:

Radiation Equivalent Man. 1 rem = 10 mSv

Activity:

Curie, the activity of 1g of pure naturally occurring Radium.

1 Ci = 3.7×10^{10} Bq.

1 mCi = 37 MBq	1 μCi = 37 kBq
1 GBq = 27 mCi	1MBq = 27 μCi
1kBq = 27 nCi	

6.2 DOSE LIMITS AND DERIVED LIMITS

The effects of ionising radiation on humans have been studied for longer and in more detail than any other carcinogen or pollutant, and it is possible to estimate with reasonable accuracy the deleterious effects of a given dose. The principle aim of radiation protection limits is to reduce the stochastic effects as far as possible. Remember that stochastic effects refer only to probabilities, such as the probability that a dose of 1 Sievert will cause a cancer.

6.2.1 Dose Limits

Limits to the effective dose equivalent for radiation workers and the general population are based on the best current data, which is that the probability of developing a fatal cancer is about 0.05 per Sievert.

The current Australian dose limits are

Radiation Workers	20 mSv per year (averaged over 5 years)
Pregnant Workers	1 mSv per year ≡ 0.75 mSv during pregnancy
General Public	1 mSv per year

These limits are over and above the normal background dose, which is about 2 mSv a year in Australia.

6.2.2 Dose Constraints

The current dose constraint set by the University for radiation workers is 1 mSv per year.

6.2.3 Annual Limit on Intake (ALI)

Once a radionuclide is taken into the body (by ingestion, inhalation or absorption) there is little that can normally be done to alter the rate of elimination or the effect of the radiation, and so the idea of a **committed dose** has developed.

It is possible from physical and biological data to estimate the dose received from ingesting a quantity of a particular radionuclide. As well as the physical half-life, the biological half-life of the element is important.

The **Annual Limit on Intake**, **ALI**, is the amount of a radionuclide that will lead to a committed dose equal to the annual dose limit of 20 mSv.

Data for the **ALI** of common radionuclides are included in Table 6.3.

6.2.4 Derived Limits

In order to help meet the ALI, concentrations of radionuclides in air and on contaminated surfaces have been established. These are termed **Derived Limits**.

Derived Air Concentration, DAC

The Derived Air Concentration is the maximum concentration of a radionuclide, which if present in air, breathed at a standard rate of 20 litres per minute for 2000 hours per year, would be equivalent to the ALI.

In most university situations, the DAC is much less important than the ALI.

Derived Limit for Surface Contamination

Contamination on surfaces can cause external irradiation of the skin and, indirectly, ingestion of the radionuclide.

The surface concentration of a radionuclide (in Bq per cm^2) which in a working year would deliver the maximum annual skin dose (500 mSv) is the **Derived Limit for Surface Contamination**. It is the contamination in Becquerel per square centimetre that will deliver 250 μSv per hour to the skin.

Data for surface contamination limits common radionuclides are included in Table 6.3.

6.3 CLASSIFICATION OF RADIONUCLIDES AND LABORATORIES

6.3.1 Radionuclides

For simplicity, the radionuclides are classified into four classes according to their hazard. The radionuclides in Class 1 are the most hazardous (e.g. alpha emitters) while those in Class 4 (e.g. tritium) are the least. The classes for the common radionuclides are included in Table 6.3.

6.3.2 Laboratories

Laboratories in which radionuclides are used are placed in three classes: **A**, **B** and **C**. The classification is based on the activity level of radionuclides that can be safely used in each type of laboratory. Type C is the common type and is the one where the least quantities of radionuclides are used. Type B is designed for medium level and Type A is for the highest level of activity.

The classification depends on:

- the class to which the radionuclides belong,
- the maximum activities used, and
- the type of operations performed.

Table 6.1 gives the range of activities that can be handled in each type of laboratory.

TABLE 6.1

Range of Activities Allowed in Laboratories

Radionuclide Class	**Laboratory Type**		
	C	**B**	**A**
1	< 400 kBq	400 kBq - 40 MBq	> 40 MBq
2	< 40 MBq	40 MBq - 4 GBq	> 4 GBq
3	< 4 GBq	4 GBq - 400 GBq	> 400 GBq
4	< 400 GBq	400 GBq - 40 TBq	> 40 TBq

The quantity of a radionuclide that will be used in a laboratory must be multiplied by the factors in Table 6.2 and the results applied to Table 6.1 to determine the laboratory class that is required. The types of radionuclides and the maximum quantities that may be used are included in the Registration Certificate for each registered area.

The University Radiation Safety Officer is responsible for the classification of registered premises.

The maximum amount of a radionuclide that can be used in a laboratory depends on the type of work being done. Working with dry, powdered material is more hazardous than simple pipetting.

The modifying factors indicate the level of precaution needed in handling the radionuclide. The modifying factor is **one** for normal chemical operations but up to one hundred times the normal quantity may be stored in the same type of laboratory.

TABLE 6.2

Modifying Factors

Type of Operation	**Factor**
Simple storage	0.01
Simple wet operations such as preparation of aliquot of stock solutions	0.1
Normal operations involving few transfers	1
Complex operations involving many transfers or complex apparatus	10
Simple dry operations (e.g. manipulation of powders)	10
Work with volatile radioactive compounds	10
Dry, dust producing operations such as grinding	100

6.4 GENERAL WORKING RULES FOR UNSEALED RADIOACTIVE MATERIALS

These general rules should be supplemented when special precautions need to be taken because of the kind of work, the total activity, or the physical and chemical properties of the radionuclides.

The main hazard is ingestion, but the external dose hazard can be high when using P-32.

Safe working techniques minimise the hazard by:

Controlling the quantities of materials used so as to limit the dose and contamination.

Containing the materials in case the unexpected event occurs.

Confirming the dose rates and lack of contamination.

6.4.1 The Laboratory

- All work with unsealed radioactive substances must be carried out in designated areas of the laboratories registered as Type C or B premises.
- Work with I-125 may require access to a Type B laboratory in another institution. More stringent rules apply to work in the Type B laboratory.
- All registered laboratories must have a radiation warning sign and contact details of the licensed supervisor(s) on each door.
- The working rules and emergency procedures must be displayed in the laboratory.
- Visits by people other than registered radiation workers should be minimised if possible.
- Visitors should be warned not to touch anything that may cause contamination.
- If possible, the laboratory should be locked when registered radiation workers are present.

6.4.2 Personal Behaviour

- Make sure that you are familiar with all the procedures necessary to handle radioactive material for your particular job, including procedures to handle spills and emergencies.
- Eating, drinking, smoking, and the application of cosmetics must not take place in the laboratory. Do not put anything in the mouth when working in the laboratory. No food or drink or utensil used to contain food or drink should be brought into the laboratory.
- You must never use your mouth for any operation. All transfers should use automatic dispensers or automatic pipettes.
- Glassblowing is not permitted in the laboratory or on glassware from the laboratory.
- Safety glasses, laboratory coats and appropriate protective gloves must be worn at all times when handling radioactive materials.
- Hands must be washed before leaving the laboratory, and no one should ever leave the laboratory wearing gloves except when carrying radioactive material.
- If you have open wounds, do not handle radioactive material without a waterproof covering on the wound.
- If you have been issued with a personal monitor (TLD) always wear it when working with radioactive material.

- Wear it correctly, do not exchange it with others, avoid contaminating the badge (if you think it is contaminated, check with the monitor, and report it to your licensed supervisor and Department Radiation Safety Officer).
- Practice new procedures with non-radioactive material, if necessary, under the supervision of your licensed supervisor.
- Do not work with a previously unused radioactive substance or vary an established procedure unless approved by the licensed supervisor and Department Radiation Safety Officer. The use of different nuclides or larger quantities may invalidate the laboratory registration.

6.4.3 Contamination

- The spread of radioactive material can be insidious and can ruin experimental results, as well as being a health hazard.
- Ingestion is readily minimized, but splashing can be a major contamination pathway.

  Splashing can easily contaminate other workers as well as yourself.

  Eyes that become contaminated are very difficult to clean.
- Work on a tray lined with absorbent material. Separate high and low activity materials on the tray into separate working areas (or onto separate trays) with the higher activities further from the operator. Use separate trays or areas for non-radioactive operations.
- Splashing can occur through bad heating methods, and because glass tubes and beakers break. Stabilise containers to prevent tipping and spillage.
- Carry out all operations that can produce vapour, dust or radioactive gas in appropriate ventilated facilities such as a fume cupboard.
- Do not handle taps, switches and handles directly. Instead, do so using disposable paper tissues. This simple precaution prevents contamination of other people and other areas.
- Take care to avoid spills when transferring radioactive material from one part of the laboratory to another, or from one laboratory to another. The material must be sealed, placed in a carrying box or well stabilised on a tray lined with absorbent material and transferred with care, preferably on a trolley - avoid collisions!
- Check contamination frequently with monitoring equipment during working procedures and carry out wipe tests to check for surface contamination when finishing a work session.
- Wash your hands before leaving an active area and monitor hands, clothing and working areas to be sure they are not contaminated.

6.4.4 External Radiation Hazard

- Use distance and shielding to reduce the dose rate to an acceptable level (normally < 2 μSv per hour).

  Check the dose rate with a monitor.
- Containers must be appropriately shielded.

  With P-32 always use Perspex shields for centrifuge tubes, pipettes and syringes.
- Avoid direct handling of pipettes, tubes or other containers of radionuclides: use tongs, forceps and tweezers.

6.4.5 Housekeeping

- Use the minimum quantity of radioactivity compatible with the objectives of the experiment.
- Containers of radioactive material must be properly sealed and clearly labeled, with the trefoil, radionuclide, activity and date. The only exception permitted by the Regulations is for very small containers.
- Do not store radioactive substances in refrigerators containing food and drink.
- Keep the radiation working area free from equipment and materials not needed for the immediate work.
- Wash all radioactive glassware etc. in sinks labeled for this purpose. Take care not to cause splashing.

6.4.6 Monitoring

- A monitor should be available so that the equipment, benches and people can be checked for contamination.

  Keep the detector in a clear plastic cover to avoid contaminating it.
- If you work with other than H-3, C-14 and S-35 always monitor your hands and clothes when leaving the laboratory.
- For H-3, C-14 and S-35, direct monitoring may have to be replaced by wipe tests.
- Regular contamination surveys must be undertaken. The frequency should depend on the level of activity used in the laboratory. For weak emitters (H-3, C-14, and S-35) the contamination survey should be done by wipe-testing the area and counting the filter paper or other wipe in a liquid scintillation counter.

6.4.7 Receiving and Storing Radioactive Material

- Records of deliveries and dispensing of radioactive materials must be kept and the records must be able to be inspected by the SA Radiation Protection Division.
- Always wipe test the interior of a delivery package and any inner container for contamination after opening the outer packaging.
- Radioactive materials must be stored with sufficient shielding to reduce any dose at the outside of the area to < 25 µSv per hour.
- Dispose of as waste, or return to storage, radioactive material that is no longer needed.

6.4.8 Radioactive Waste

- Solid radioactive waste must be kept separate from normal laboratory waste and must NOT be sent out with the normal waste. The Department Radiation Safety Officer and University Radiation Safety Officer are responsible for its disposal.
- Liquids in sealed scintillation vials are treated as solid waste.
- Liquids that are not miscible with water must be stored so that they can be sent out with the solid radioactive waste.
- Liquids that are miscible with water may be put down the designated sinks in the amounts permitted by the University's Approved Radioactive Waste Management Plan.

- Sinks and plumbing used for the disposal of radioactive material must be labelled and a notice must remind workers that a flush of at least 15 litres of water is required every time radioactivity is released to the sewer.

6.4.9 Emergencies and Accidents – Unsealed Radioactive Material

If the Emergency Services are called, ALWAYS inform them that the emergency is in an area using radioactive material.

6.4.10 Radioactive Spills

Any loss of control of radioactive material is an abnormal situation and spills will produce contamination of laboratory benches and equipment, and in more serious cases, the floor and people.

Spill kits must be available in registered laboratories. Suitable kits are listed in Part 6.

Remedial Action

- Stop and secure the operation that caused the spill.
- Warn others.
- Isolate and absorb the spill and secure the spill area.
- Do not do anything that will spread the material further.
- Work from the outside in to remove the spill and minimise the spread of contamination.
- If necessary, temporarily seal the contamination with plastic sheet until ready to decontaminate the area.
- Treat all cleaning materials as radioactive waste.
- Check for the contamination of people, then furniture, and finally equipment.
- Inform your licensed supervisor and Department Radiation Safety Officer, who will inform the University Radiation Safety Officer if necessary.

6.5 RADIATION EMERGENCIES, ACCIDENTS AND INCIDENTS

6.5.1 Radiation Emergencies

Radiation Emergency means a situation in which a source of ionising radiation is out of control to such an extent that the continued exposure of a person to excessive amounts of ionising radiation while the source of ionising radiation remains out of control is unavoidable unless the normal functions or operations of the facility or place in which the source of ionising radiation is being used are grossly disrupted. For the purposes of this definition "excessive amounts of ionising radiation" means effective doses or intakes of radioactive substances that, if continued for the normal hours of occupancy of the facility or place for three months, would result in an exposure contrary to Division 2 of Part 2 in the Regulations;

Examples of Radiation Emergencies include:

- contamination that has spread beyond a laboratory bench,
- a person has been contaminated,
- radioactive material has been ingested, and
- a person is believed to have received a large radiation dose.

[The Regulations also define a Radiation Emergency as a situation in which a person is likely to receive in three months more than the annual limit of exposure (worker or general public). An official radiation emergency of this kind is very unlikely in a Type C laboratory.]

6.5.2 Radiation Accidents

A loss of control of a source of ionising radiation where control is not fully regained, or a significant dispersal of radioactive material takes place, or a person is likely to receive a dose or intake that is at least twice that normally received in the work with that source.

A radiation accident is most unlikely in a Type C laboratory using unsealed radioactive materials; the risk is increased if large quantities of Na-22, P-32 or I-125 are involved.

6.5.3 Radiation Incidents

These are situations in which a source of ionising radiation is temporarily out of control, but no significant dispersal of radioactive material takes place and no person receives a dose or an intake of material more than twice that likely in normal operations. Typical levels for incidents are

Ingestion	> 500 kBq of C-14, P-32, P-33, S-35, or >50 kBq of I-125
Dispersion	> 5 MBq of C-14, P-32, P-33, S-35, or >500 kBq of I-125.

6.5.4 Ingestion

If you believe that you have ingested radioactive material contact your Department Radiation Safety Officer immediately.

If the ingestion is from spilt material, warn others present, leave immediately and secure the laboratory to prevent others entering. Contact the Department Radiation Safety Officer.

6.5.5 Exposure

Exposure to a dangerous external radiation field is unlikely with the unsealed sources used in the University.

If an over-exposure is suspected, warn others present, leave immediately and secure the laboratory to prevent others entering. Contact the Departmental Radiation Safety Officer.

6.5.6 Summary of Emergency Actions

In general, operate in the order:

1. manage any injury
2. assess the situation - think before acting
3. evacuate the area if necessary
4. advise – the supervisor, and the Department and University Radiation Safety Officers
5. control the radiation hazard
6. clean up and decontaminate in the order
    - people,

- laboratory, and
- equipment

7. report the incident in accordance with the **university Incident reporting and investigation** procedure. This includes:
   - immediate notification by telephone to the University Radiation Safety Officer (830 22703) or the Safety & Wellbeing Team (830 22459) if it is known or suspected that the incident may be a 'radiation emergency' or 'radiation accident', in which case the Safety & Wellbeing Team will notify the EPA as soon as reasonably practicable
   - log details of the incident using the online **Hazard & Incident Reporting & Investigation System** on the Staff Portal.

   Verbal and electronic reporting should include
   - the time, date and place. The names of those involved, including any one who may have been affected by the incident,
   - the quantity of radioactive material involved, its physical and chemical form and the extent of any dispersal of a radioactive substance. It is important to estimate the amount of activity involved in becquerels (or Curies) so that it can be compared with the ALI, and other limits,
   - the length of time the radioactive material was out of control and when it was reported to a Radiation Safety Officer, and
   - the probable cause of the incident.

6.5.7 Decontamination

Successful decontamination begins by moving from the mildest methods to more aggressive ones. It is very important to be gentle when decontaminating people as violent methods can cause the contamination to pass through the skin, making the situation much worse. The contaminated area should be monitored throughout the decontamination process.

General

Physical methods

ALWAYS use these first.

- Wiping, then scrubbing, then abrading (CARE).
- Be careful not to spread the contamination.

Chemical treatments

Use these more drastic methods after simple physical methods have failed.

- Acids/alkalis.
- With carrier chemicals of the same kind.
- With complexing agents.

Personal Decontamination

Skin

- Monitor the skin, and get help if necessary; an assistant to monitor the progress is very helpful.
- Remove contaminated clothing if necessary, and secure in a plastic bag.
- Rub with paper towels, warm water and mild soap, then monitor again.

- Scrub - soft brush – do not damage the skin, then monitor again.
- Use a decontamination product like ‘Count-off’.
- If still contaminated, rinse in saturated $KMnO_4$ (this removes dead skin – use once only).
- If still contaminated – get advice.

Face and Eyes

- These may be very difficult to decontaminate.
- Wash only with warm water or sterile saline solution.
- Be careful not to swallow or inhale contamination.
- If washing with water does not remove the contamination, call the Department and University Radiation Safety Officers.

Other Parts of the Body

- Do not spread contamination – don’t shower with contaminated hair.
- Rinse rather than scrub.
- Encourage bleeding from small wounds.
- Package contaminated clothing – do not leave the laboratory in contaminated clothes, but arrange for a new set!

Wounds

- Wash only with warm water.
- Bleeding may help to remove contamination.
- If washing with water does not remove the contamination, call the Department and University Radiation Safety Officers.

Ingestion and Inhalation

- Internal contamination requires professional medical assistance.
- **You must call the University Radiation Safety Officer IMMEDIATELY.**

Laboratory Decontamination

For items like trays, benches, equipment and the floor.

- Restrict access until cleaned up.
- Mop the spill with tissues and dry the surface.
- Monitor.
- Decontaminate any remaining hot spots by working from outside inwards with Decon 90; scrub if needed.
- Do not contaminate the cleaning solution – use paper towels/tissues only once.
- Not all contamination may be removed by cleaning if the material exchanges with the surface, and exchange with normal material should be tried.

The Department and University Radiation Safety Officers must supervise more serious clean-up operations.

Spills Kits

These kits are the minimum for effectively dealing with the immediate effects of a spill.

General Type C Laboratory

- Gloves and plastic/paper overshoes.

- Absorbent material (paper towels, tissues).
- Plastic bags and pails for waste.
- Household detergent and Decon-90.
- Tweezers or forceps.
- Masking tape, hazard tape and marking pens.
- Self-adhesive "Radioactive" labels and radiation warning signs.

Type C Laboratory Using I-125

Because of the hazard of producing volatile elemental iodine by oxidation of iodine compounds, the kit must contain a reducing agent for immediate treatment of spilled material. This solution should be easily available at all times in a laboratory using I-125 as well as in the spill kit.

- The materials in the general spill kit.
- A bottle containing alkaline sodium iodide/sodium thiosulfate solution (0.1 mol/l NaI, 0.01 mol/l NaOH and 0.1 mol/l $Na_2S_2O_3$) that can be applied to a spill area.

6.6 GENERAL WORKING RULES FOR X-RAY ANALYSIS UNITS

6.6.1 The Laboratory

- The door must carry the radiation warning sign, "Danger - Radiation Area", and the contact details of the licensed or authorized operator(s).
- The working rules and emergency procedures must be displayed in the laboratory.
- Visits by people other than registered radiation workers should be minimised if possible.
- Visitors should be warned not to touch the control panel.
- The laboratory should be locked when no registered radiation worker is present and must be locked when the X-ray unit is operating unattended.
- Only authorized and licensed people may operate the X-ray equipment.

6.6.2 Personal Behaviour

- Make sure that you are familiar with all the procedures necessary to operate the X-ray analysis apparatus.
- Do not vary an established procedure unless approved by the licensed supervisor of the X-ray apparatus.
- With partly enclosed or open beam units, practice any new procedures with the X-ray unit turned off, until you are sure the procedure will not bring your body into the primary beam. Minimize any exposure to leakage and scattered radiation.
- Never make any adjustments to samples, crystals, or goniometers while the X-ray beam is in the operation mode unless a licensed person is present who can watch to make sure that you do not place yourself in danger.
- Alignments must not be carried out visually while the X-ray tube is energised, unless a viewing system is used which is shielded to prevent exposure of the eye or other parts of the body to the primary beam.
- Inexperienced persons may only operate the apparatus under direct supervision of an experienced operator.

- If you have been issued with a personal monitor (TLD) always wear it when working with the X-ray unit.
- Wear it correctly and do not exchange it with others.

6.6.2 Operational Rules

- Check that all warning lights are operational before the unit is energised.
- Avoid exposing any part of the body to the primary beam - fingers and eyes especially.
- Monitor the apparatus when the X-ray tube is operating - remember that a fault may have developed since you last used the equipment.
- Immediately turn off the machine if it appears that the situation may be hazardous (equipment failure, misalignment, misplaced shielding etc.).
- The X-ray analysis unit must not be operated with the safety interlocks bypassed or with part of the shielding removed without prior approval of the Department Radiation Safety Officer, who will inform the University Radiation Safety Officer that this is being done.

6.6.3 Monitoring and Safety Checks

- A monitor must be available which is suitable for the X-ray energy and is calibrated so that it can properly identify an absorbed dose of 1 μGy per hour.
- Regular radiation monitoring of the x-ray analysis units must be carried out. The required six monthly interval is generally too long in a university situation with changing experimental arrangements.
- Monitoring must be done every time the experimental arrangement changes.
- Monitoring must be done after any radiation incident or accident involving the apparatus.
- A record must be kept of all the radiation surveys.
- Checks of all the interlocks and warning lights must be carried out at least every 6 months.

Personal monitoring

- Personal monitors are not very good indicators of exposure to the narrow direct beams of radiation from X-ray analysis units.
- Personal monitors are useful for checking the exposure of persons to leakage and scattered radiation from X-ray units.
- All operators of X-ray analysis units must wear a TLD badge.

6.6.4 Emergency Procedures

If the Emergency Services are called ALWAYS inform them that the emergency is in an area where an X-ray generator is normally in use. Make sure they are informed that EITHER the X-ray unit is turned off and is safe OR that it is still operational and special precautions will be needed [this should be an extremely rare event].

6.6.5 Remedial action: Exposure to the Primary Beam

- Switch off the X-ray analysis unit.
- Refer the exposed person for medical examination.
- Do not take action to correct the fault that caused the exposure. It will be difficult to estimate the absorbed dose if the fault has been corrected.

- Leave a sign on the unit to indicate that the unit should not be used or altered in any way.
- Disconnect the unit from the power and lock the room.
- If an accidental exposure has occurred it is important to obtain an accurate assessment of the dose received. The University Radiation Safety Officer will obtain specialised advice on the dose estimation, based on the incident report.

6.6.6 Summary of Emergency Actions

- Turn off the machine.
- Manage any injury.
- Advise the supervisor and the Department Radiation Safety Officer.
- Report the incident in accordance with the university **Incident reporting and investigation** procedure. This includes:
  - immediate notification by telephone to the University Radiation Safety Officer (830 22703) or the Safety & Wellbeing Team (830 22459) if it is known or suspected that the incident may be a 'radiation emergency' or 'radiation accident', in which case the Safety & Wellbeing Team will notify the EPA as soon as reasonably practicable
  - log details of the incident using the online Hazard & Incident Reporting & Investigation System on the Staff Portal.

Verbal or electronic reports should include the following details about the incident:

- the time, date and place
- the names of those involved, including any one who may have been affected by the incident
- the results of any dose assessments that have been made, and
- the probable cause of the incident.

6.7 GENERAL WORKING RULES FOR SEALED RADIOACTIVE SOURCES

These apply to all sealed sources. Some special rules apply for neutron moisture meters and other sealed sources that are used away from fixed locations or laboratories

6.7.1 Sealed sources

- The sources must be stored in a locked room with a sign "Danger Radiation", the name and telephone number of the licensed person responsible for the sources and the radiation symbol.
- Only licensed persons may use the sources without supervision. Non-licensed people may use the sources under the direct supervision of a licensed person.
- A source register is to be maintained for the purpose, so far as possible in identifying the location of the sealed source at any given time. The source register must contain:
  - the registered number of the source,
  - If the source is moved in a vehicle – the registered number of the vehicle,
  - the location where the source is to be used,
  - the times and dates of removal and return,

- the name of the licensed person responsible for the source while it is away from the storage location, and
- the signature of the responsible person against both the removal and the return of the source.

- A record should be kept of the use of the sources - this may be part of the official source register.
- Arrangements must be made for the sources (or housings if the source is not accessible) to be wipe tested regularly. The results of the tests must be recorded in the source register.

6.7.2 Monitoring and safety checks

- In general, everyone using a sealed source which is not fully enclosed at all times and which can deliver a dose of 0.5 μSv per hour to the body, to wear a personal monitoring device (TLD).
- The dose rate at the operator location when the source is in use must be monitored at the beginning and end of each period of use. The dose rates should be recorded. The monitor must be calibrated annually.
- If the source mechanism includes interlocks, mechanical shutters, source transport mechanisms and so on, these must be checked regularly.

6.7.3 Emergency action

The proper responses to an emergency involving a sealed source can be divided into two categories:

- **Category 1:** The source is temporarily 'loose' from its proper housing or shielding but the dose to the operator is less than 500 μSv per hour (about 10 μSv per minute). In these circumstances it may be possible to recover control within a few minutes (operator dose < 200 μSv). It is important NOT to spend too much time trying to remedy the situation - assess the chance of rapid recovery and if it is likely to take more than a few minutes treat the situation as **Category 2**.
- **Category 2:** The source cannot be returned to its proper storage configuration due to failure of mechanical or electrical actuators. This is a serious emergency and the source should be left, the room locked and secured, warning signs posted, the immediate area taped off and if necessary an area around the source room evacuated. Evacuation will be necessary if a dose rate of > 0.5 μSv per hour can be measured outside the secure area.

In all cases, the University Radiation Safety Officer (830 22703) or the Safety & Wellbeing Team (830 22459) must be telephoned immediately (if unavailable, call the Radiation Protection Division, EPA, on 8463 7826). Security must be alerted if an area is evacuated or taped off. Make sure that the radiation field in accessible areas is < 0.5 μSv per hour. Record, as soon as possible, the events leading up to the loss of control and the present location of the source, condition of the source housing, etc. so that plans for recovery can be made.

Some other circumstances may threaten the source - fire may destroy or remove the shielding, or a flood may cause corrosion of the sealed housing. These cases require a careful, monitored approach to the source room and the source; generally these events will not breach the integrity of the source housing.

6.7.4 Neutron Moisture Meters

Operations

- The meter must be stored in a locked room with a sign 'Danger Radiation', the name and telephone number of the licensed person responsible for the meter and the radiation symbol.
- Only licensed people may operate the neutron moisture meter away from university campus areas. On campus, non-licensed people may operate the meter under the direct supervision of a licensed person.
- Every use of the meter must be recorded in a logbook with details of time, date, place and operator, if being transported by a vehicle the registration number of the vehicle must also be recorded.
- The source should only be released from the shield into an appropriate soil borehole for measurements. It is dangerous to allow the source to be unnecessarily exposed.
- The mechanical operation of the meter should be checked every time it is used. Any problems must be recorded in the log and reported.

Personal Behaviour

- Make sure that you are familiar with all the procedures necessary to operate the neutron moisture meter.
- Do not vary an established procedure unless approved by the licensed supervisor of the meter.
- Everyone who uses the neutron moisture meter must wear a suitable personal monitor that will respond to the neutron dose.
- Wear it correctly and do not exchange it with others.
- Never make unauthorised adjustments to the meter and never attempt to remove the source from the housing.
- Make sure that you are familiar with the emergency procedures to be followed if the source is jammed or becomes detached, or the probe cannot be removed from the soil. In field situations, operators have the ultimate responsibility for their own safety and that of others.

Operational Rules

- Monitor the meter on removing it from its carrying case, and again when in use. Remember that a fault may have developed since you last used the equipment.
- Immediately assess the situation if it appears hazardous (equipment failure, misalignment, mechanical problems, etc).

Monitoring and Safety Checks

- ***Personal Monitoring***

  Everyone using a neutron moisture meter must wear a personal monitoring device that measures neutron doses. Normal TLD dosimeters do not respond to neutrons. Neutron doses can be calculated from the tracks left by neutrons in special plastic. The appropriate Department Radiation Safety Officer arranges for these special badges.

- ***Source Monitoring***

  The purpose of monitoring the source is mainly to make sure that the shielding is intact and the source is properly housed inside the shield. Because of the gamma-radiation emitted by the source, a gamma-ray monitor can be used for routine measurements. For most americium-241/beryllium neutron moisture meters, the total effective dose rate (gamma plus neutron) is about twice the gamma-ray dose rate.

The moisture meter should be monitored:

- whenever it is removed from its carrying case,
- when first used each day check the dose rate in the closed and operational positions and that the mechanical operation is normal, and
- at the end of a day's operations when it is returned to the carrying case.

The mechanical operation of the meter must be checked each time it is used.

Transport and Field Use

Neutron moisture meter and soil density gauges are the largest sources carried off the campus and because of the potential hazard in case of a road accident, and the possibility of the source being stolen, these transport and field rules must always be followed. More detailed information on transporting radioactive material can be found in a bulletin from the Radiation Protection Division.

Transport Arrangements

A holder for the gauge carrying-case must be securely restrained in the vehicle and the gauge must not be able to break loose in normal situations.

The holder must be able to be securely locked and carry signs saying "Danger - Radioactive" with the radiation symbol and the name and telephone number of the person responsible for the source.

The gauge must not be transported in the passenger compartment of the vehicle and must be carried as far as possible from the driver and any passengers.

The gauge must be transported in its carrying-case with the source locked in the shielded or “OFF” position.

Temporary Storage

To prevent unauthorized access to the gauge the vehicle should not be left unattended.

The source should be removed from the vehicle and stored in a secure locked location at night.

If the source must be left in the vehicle overnight, the vehicle should be parked in a locked garage or shed.

The warning signs required for transport are sufficient when a vehicle is used as a temporary store.

Vehicle Labels and Notices

The vehicle must be labelled with 3 vehicle labels of the type described in the Code of Practice for the Safe Transport of Radioactive Substances Commonwealth, 1990.

A signed and dated consignment note must go with the source. In most cases, when a source is transported for university work, the consignor and consignee will be the same.

A notice must be carried in the glove-box giving details of the source, the phone number of the University Radiation Safety Officer and the emergency phone number of the Radiation Protection Division **000.**

Emergency Action

- ***Vehicle Accident***

  In the event of an accident or emergency, the person in charge of the motor vehicle, or another responsible person, must notify the University Radiation Safety Officer (830 22703) or the Safety & Wellbeing Team ((830 22459), and the Radiation Protection Division EPA (8463 7826) as soon as possible.

  If the source is properly secured in the vehicle it will not be a major hazard in most road accidents as it will remain in the holder in its carrying case. Emergency Services are trained to handle a situation involving a radiation source, **but they must know there is a source in the vehicle**.

- ***Source Container Breakdown***

  The mechanical breakdown of a meter in the field can be more difficult to handle than the same problem on campus because the proper resources may not be as easily available.

  When used in the field:

  - emergency signs and warning tape must be carried so that the source area can be marked off if mechanical failure occurs,
  - mark the area around the broken source as a radiation hazard,
  - monitor the area outside of the marked area,
  - inform Emergency Services (**000**), the University Radiation Safety Officer and the Radiation Protection Division, and
  - do not leave the source unattended unless help cannot otherwise be obtained.

- ***Lost or jammed probe***

  In the advent that a probe becomes lost down a borehole due to the retrieval cable breaking or the probe becomes jammed in the borehole the following must occur:

  - inform the Department and University Radiation Safety Officers, and the Radiation Protection Division (EPA),
  - do not leave the source unattended unless help cannot otherwise be obtained, and
  - monitor the area to ensure that no accessible area to the public exceeds 25 μSv per hour. Readings and locations must be recorded to assist in future investigations.

- ***Logging the incident***

  - After the emergency is brought under control, log details of the incident using the online **Hazard & Incident Reporting & Investigation System** on the Staff Portal.

6.8 TRANSPORT OF RADIOACTIVE MATERIALS

The transport of radioactive materials increases the hazard because of the potential for an accident in which the material is out of control, very likely in a public place such as a road. The SA transport regulations 2003 and the national Code of Practice for the Safe Transport of Radioactive Material (2001) (which incorporates the International Code) must be followed in every case. The EPA has a webpage on Radiation: Transportation of Radioactive Materials.

TABLE 6.3 - PROPERTIES OF SOME COMMONLY USED RADIONUCLIDES

Nuclide	Class	Physical Half-life $t_{1/2}$ days	Biological Half-life $t_{1/2}$ days	Effective Half-life $t_{1/2}$ days	Main Radiation Type	Energy MeV (Max for beta)	Gamma ray dose rate from 1MBq at 10cm, µGy/hr[1]	Ingestion ALI MBq	Suggested Shielding for a Factor of 0.1	Surface Contamination Limit Bq/sq cm
H3	4	12.3 yr	12	12	β	0.018		1000		1000
C14	3	5730 yr	10	10	β	0.156		40		1000
Na22	2	2.6 yr			β+ γ	0.546 1.275, 0.51	36	10	37 mm Pb	100
P32	3	14.3 dy	241	13.5	β	1.7		8	10 mm	100
P33	3	25.4 dy	241	23	β	0.248		80	10 mm	100
S35	3	87.4 dy	70	39	β	0.17		70	10 mm	1000
Cl36	2	$3x10^5$ yr			β	0.71		20	10 mm	1000
Ca45	2	163 dy			β	0.26		10	10 mm	1000
Cr51	3	27.7 dy	670	26.6	EC	γ 0.32	0.6	400	7 mm Pb	1000
Mn54	2	312.7 dy			EC	γ 0.84	13.8	25	25 mm Pb	1000
Fe55	3	2.7 yr			EC	γ 0.006		100	1 mm Pb	1000
Fe59	3	45 dy			β γ	0.46 1.1	17.9	10	44 mm Pb	1000
Co57	3	270.9 dy	9	8.7	EC	γ 0.122	4.1	60	2 mm Pb	1000
Co60	3	5.26 yr			β γ	0.31 1.17, 1.33	37	3	40	
Ni63	3	100 yr			γ	0.067		100		100
Cu64	3	12.7 hr			β+ γ	0.64 0.51	3.6	150	12.5 mm Pb	100
Zn65	3	244 dy			β γ	0.33 0.115	8.9	5	5 mm Pb	1
Se75	3	120 dy			γ	0.265	23	50	5 mm Pb	100

Continued on next page

[1] Source: The Health Physics and Radiological Health Handbook revised edition 1992. Edited by Bernard Shleien et al.

TABLE 6.3 continued
PROPERTIES OF SOME COMMONLY USED RADIONUCLIDES

Nuclide	Class	Physical Half-life $t_{1/2}$ days	Biological Half-life $t_{1/2}$ days	Effective Half-life $t_{1/2}$ days	Main Radiation Type	Energy MeV (Max for beta)	Gamma-ray dose rate from 1MBq at 10cm, μSv/hr	Ingestion ALI MBq	Suggested Shielding for a Factor of 0.1	Surface Contamination Limit Bq/sq cm
Rb86	3	18.7 dy			β γ	1.78 1.08	1.5		30	
Sr90	2	29 yr			β	0.66		6		10
Mo99	3	2.8 dy			β γ	1.21 0.74	3.1	20	20 mm Pb	1000
Tc99m	3	6.0 hr			γ	0.14	3.3	1000	1 mm Pb	1000
Cd109	3	464 dy			EC γ	 0.062	5.0	10	1 mm Pb	100
I125	2	60.1 dy	138	41.8	γ	0.035	7.4	1	0.2 mm Pb	100
I131	2	8.0 dy	138	7.6	β γ	0.61 0.08	7.6	1	11 mm Pb	100
Cs137	2	30 yr			β γ	0.51 0.66	10.3	1	20 mm Pb	100
Ir192	2	74 dy			β γ	0.67 0.32	16	10	25 mm Pb	1000
Hg203	3	46.6 dy			β γ	0.21 0.28	6.8	10	10 mm Pb	
Am241	1	432 yr			α,γ	0.06	8.5	0.1		0.1
Th-nat*	4	1.4 x 10^{10} yr			α,β γ	2.26 2.61	 34	 0.2	 75 mm Pb	
U-nat*	4	4.5 x 10^{9} yr			α,β γ	2.29 1.76	 15	 0.3	 60 mm Pb	

*Th and U assumed to be in equilibrium - the gamma doses are smaller if thoron/radon and immediate daughters are not present

NOTE The suggested shielding should always be checked in practice

PART 7 - SUMMARY OF REGULATORY REQUIREMENTS

This is a brief outline of the legal obligations of radiation workers and the employer. Full details may be found at EPA legislation and regulations. Legislation controlling the use of ionising radiation in South Australia includes the

- Radiation Protection and Control Act 1982
- Radiation Protection And Control (Ionising Radiation) Regulations 2000.
- Radiation Protection and Control (Transport of Radioactive Substances) Regulations 2003.

The legislation imposes responsibilities on a wide range of people, such as those who use or handle radioactive substances or operate x-ray equipment (radiation workers), the employers of radiation workers, the occupiers of premises in which unsealed radioactive substances are handled or kept, and the owners of irradiating apparatus such as X-ray apparatus.

In general, the University of South Australia is the employer, occupier and owner.

7.1 SOME DEFINITIONS

A **Radiation Worker** is a person who uses any source of ionising radiation or is directly involved in an activity in which a source of ionising radiation is used and who may be exposed to ionising radiation from the source.

Post-graduate students and visiting academic staff or research workers who use ionising radiation are radiation workers even if not employed by the University.

A **Radiation Incident** is an occurrence in which a source of ionising radiation is temporarily out of control, but in which no significant dispersal of any radioactive substance takes place and no person is likely to have received an equivalent dose or an intake of any radioactive substance more than twice that which is likely to occur during any normal operation. An abnormal occurrence involving radioactive substances is not regarded as being a radiation incident unless:

- a radioactive substance is swallowed by a person and the activity swallowed exceeds

for group 1 radionuclides	5 kBq
for group 2 radionuclides	50 kBq
for group 3 radionuclides	500 kBq
for group 4 radionuclides	5 MBq

or

- the activity of the radioactive substance involved exceeds

for group 1 radionuclides	50 kBq
for group 2 radionuclides	500 kBq
for group 3 radionuclides	5 MBq
for group 4 radionuclides	50 MBq

A **Radiation Accident** is an occurrence in which a source of ionising radiation is out of control and, either

- control over the source of ionising radiation is not totally regained, or
- a significant dispersal of radioactive substances takes place, or
- a person receives or could receive an equivalent dose or an intake of radioactive substances at least twice the amount that is likely to be received during the course of normal operations.

A **Significant Dispersal** is one where the activity of the dispersed radioactive substance exceeds the following amounts:

for group 1 radionuclides	50 kBq
for group 2 radionuclides	500 kBq
for group 3 radionuclides	5 MBq
for group 4 radionuclides	50 MBq

A **Radiation Emergency** is a situation in which a source of ionising radiation is out of control to such an extent that the continued exposure of a person to excessive amounts of ionising radiation is unavoidable unless the normal operations of the facility in which the source of ionising radiation is being used are grossly disrupted. An excessive amount of ionising radiation is that which, if continued for the normal hours of occupancy of the facility for three months, would result in a dose greater than 20 mSv per year to the radiation worker.

7.2 LEGAL RESPONSIBILITIES

7.2.1 Responsibilities of Radiation Workers

A radiation worker must:

- obey all safety signs,
- act responsibly in a way that is not likely to result in a radiation incident, radiation accident or radiation emergency,
- report to their supervisor any fault in radiation devices or equipment (such as X-ray apparatus) they use,
- report any radiation incident or accident using the Incident Reporting and Investigation System, and in the case of a radiation accident notify The Safety & Wellbeing Team as soon as reasonably practicable,
- perform operations and use radiation protection equipment in the manner described in the Regulations and in the Radiation Safety Manual, and
- in the case of a woman, upon learning of her pregnancy, inform OHS&W of her pregnancy.

A radiation worker to whom a personal monitoring device (such as a TLD badge) is issued must wear the personal monitoring device properly and not permit any other person to wear their monitoring device.

7.2.2 Responsibilities of Employers, Owners and Occupiers

Licences and registrations

In South Australia all persons who want to operate X-ray equipment, or use or handle radioactive substances, must hold an appropriate licence issued by the EPA. Employers have an obligation to ensure that no unlicensed worker uses ionising radiation or works in unregistered premises.

The EPA imposes conditions on the licence related to the knowledge of the applicant and it is very important that licensees are familiar with the conditions of their licence. The licences must to be renewed annually.

The Act makes provision for groups of people whose work with radioactive substances is such that licensing is not warranted. As an example, persons who handle unsealed radioactive substances in Type C premises while they are working under the directions of a licensed supervisor do not need a licence but must still have a good knowledge of radiation protection principles and the safe handling of radionuclides.

The owner of irradiating apparatus and the occupier or owner of premises in which radioactive substances are used or stored must register the apparatus and premises with the EPA. An employer must make sure employees do not use unregistered apparatus, or work in unregistered premises.

Resources for Radiation Safety

The employer must provide radiation monitoring equipment, protective clothing, fume cupboards, signs, labels and any other necessay radiation protection equipment for the use of radiation workers, and ensure that the equipment or devices are kept in good working order and condition.

The employer must issue a radiation worker with an EPA approved monitoring device (such as a TLD badge) for measuring personal radiation exposure. The EPA has the power to exempt an employer from this requirement and many specific exemptions exist for groups such as undergraduates in certain courses, those using particular radioactive substances in laboratories where there is a negligible risk of exceeding a small fraction of the annual dose limit, and those using fully enclosed X-ray analysis apparatus.

A radiation record must be kept for each radiation worker and be made available to the worker.

The personal radiation record must contain:

- full name, sex and date of birth of the radiation worker,
- current address,
- date of commencement of employment,
- kind of work performed,
- details of type of ionising radiation to which the worker may have been exposed,
- monitoring device worn by the radiation worker, and
- the monitoring results for each wearing period, cumulative result since the beginning of the calendar year, cumulative result for each calendar year and cumulative result for previous calendar years.

The employer must make available to the University Radiation Safety Officer the equipment, time and assistance (such as an Administrative Officer, and Department Radiation Safety Officers), necessary to enable the duties under the legislation to be performed satisfactorily.

Information and Training

Before a worker first commences any duties as a radiation worker the employer must:

1. inform the worker of the potential hazards from ionising radiation, of the names of the University Radiation Safety Officer and of the Department Radiation Safety Officer with responsibilities in the area of the worker's duties,

and

2. inform the worker of all safety arrangements that have been made to protect them from the effects of ionising radiation, and give directions in the form of working rules to such worker as to all steps to be taken to achieve the ALARA principle and make available for perusal a copy of the Act, the Regulations and the Radiation Safety Manual. Appropriate radiation safety training must be provided and recorded.

Dose Limits

An employer must not permit any radiation worker to be exposed to an annual total dose in excess 20 mSv (averaged over 5 years with a maximum of 50 mSv in any one year), or a member of the public to be exposed to an annual total dose in excess of 1 mSv. If a pregnant radiation worker has informed the employer of her pregnancy, the unborn child must not receive an effective dose greater than the maximum for a member of the public (0.75 mSv over nine months). These dose limits have been decreased to the lower dose constraints at this university.

Faulty Equipment

Where an employer discovers a fault or defect in any device such as x-ray apparatus, radiation monitoring equipment, radiation signs and labels or any other radiation protection equipment or device, which is likely to increase the exposure to ionising radiation of anyone, the employer must immediately inform all who use the device of the fault, and have the fault or defect remedied as soon as possible.

7.3 REPORTING & INVESTIGATION OF RADIATION INCIDENTS AND ACCIDENTS

7.3.1 Reporting radiation incidents and accidents

A radiation worker **must report any radiation incident/accident** in accordance with the university **Incident reporting and investigation** procedure. This includes:

- **notify** the Department Radiation Safety Officer and the University Radiation Safety Officer (see page 1 Key Contacts) **as soon as possible after becoming aware of the incident** giving**:**
  - full details of the radiation incident including the time and place it occurred
  - the probable cause
  - the extent of any loss of control of the source or any dispersal of radioactive material
  - possible effects and
  - the name of any person likely to have been affected by it.
- **alert** Security and/or Building Evacuation Officers if an area needs to be isolated or evacuated
- **log details** of the incident using the online **Hazard & Incident Reporting & Investigation System** on the Staff Portal.
- A more detailed, signed report can be attached to the electronic incident report before submission, or by the incident investigator or the Safety & Wellbeing Team after initial submission.

If more than one radiation worker is involved it is not necessary for each worker to report the incident, provided that a written report is made and each of the radiation workers involved in the incident/accident has assisted in compiling the report and each of them has signed the report.

The regulatory requirements for reporting of radiation emergencies, accidents and incidents are slightly different. However, as it not always apparent at the time of an incident what definition applies, the reporting requirements set out in this procedure are the same for incidents and accidents.

The University Radiation Safety Officer or the Safety & Wellbeing Team will immediately notify the EPA of reportable incidents, and forward a copy of a written report to the EPA within 7 days. The following kinds of events must be reported to the EPA:

- a radiation emergency
- a radiation accident in which control is not fully regained
- the loss or theft of any X-ray apparatus
- the loss or theft of any radioactive substance with an activity in excess of the following amounts:

for group 1 radionuclides	50 kBq
for group 2 radionuclides	500 kBq
for group 3 radionuclides	5 MBq
for group 4 radionuclides	50 MBq

or

- damage to any sealed radioactive source resulting in leakage or suspected leakage of its contents.

7.3.2 Investigation of Radiation Incidents and Accidents

The Head of School or Research Institute Director must, under the guidance of the University Radiation Safety Officer and any Department Radiation Safety Officer, undertake an investigation of each radiation incident or accident. The investigation is to be recorded using the Incident Reporting and Investigation System in accordance with the OHSW Incident/Hazard Reporting and Investigation Procedure.

7.3.3 Register of Radiation Incidents and Accidents

The University Radiation Safety Officer will maintain a register of radiation incidents and accidents. The register shall include:

- the date, time and place of the incident/accident,
- the name of any radiation worker involved in the incident/accident,
- full details of the incident/accident, including the probable cause, the length of time the source of ionising radiation was temporarily out of control, the extent of any dispersal of any radioactive substance that may have occurred and the name of any person involved, and in the case of an accident, the estimate of equivalent doses received by any person, the time it was reported to the radiation safety officer and the probable cause
- the result of any investigation undertaken in respect of the incident, and
- details of any steps that have been taken to minimise the possibility of any further incident occurring.

7.4 CONTINGENCY PLANS

The employer must prepare a contingency plan for every operation or process which involves ionising radiation. The plans must take into account every radiation accident and radiation emergency that is reasonably foreseeable, and contain instructions as to how to deal with these events with particular regard as to how control may be restored and the exposure of persons may be kept to a minimum. The contingency plans should be incorporated in the radiation safety manual, and all the necessary equipment for the effective operation of each of the plans must be available.

7.5 EXPOSURE TO VOLUNTEERS INVOLVED IN MEDICAL RESEARCH

Both the EPA and the UniSA Human Research Ethics Committee require that researchers conform with the national Code of Practice for the Exposure of Humans to Ionizing Radiation for Research Purposes (2005).

In South Australia, no person may undertake research involving the exposure to ionising radiation of human beings without first obtaining the approval of the EPA and the consent in writing of the person(s) involved. This approval is in addition to any approval required by the University's Research Ethics and Safety Committee.

The application to the EPA must include full details of the research and the reason why it is necessary to expose a person to ionising radiation for the purpose of research, the number of persons who may be exposed to ionising radiation, and the extent to which they may be exposed.

The application must also include the possible benefits of the research to the community, the steps to be taken to monitor the levels of ionising radiation, and the precautions that will be taken to keep the exposure to a minimum.

Some schools or research centres have an exemption whereby they can simply notify the EPA of the research project rather than seek prior approval, subject to approval by the University Radiation Safety Officer and the Human Research Ethics Committee.

EPA application/notification forms are available from the University Radiation Safety Officer.

7.6 RADIOACTIVE WASTE

No one can dispose of radioactive waste without first obtaining the approval of the Radiation Protection Division, EPA.

An application for approval to dispose of unsealed radioactive substances must be made by the registered occupier of the premises in which the substances are kept or handled (the University) and must contain details of the substances to be disposed of including their chemical and physical form, the maximum activities likely to be disposed of, and the arrangements to prevent these maximum activities from being exceeded.

The application must also contain details of the place(s) and approximate date(s) for the disposal and details of the method of disposal including packaging, storage, segregation, labelling, monitoring and transport, and the names of those who will handle the substances during the course of the disposal.

PART 8 - REFERENCE MATERIAL

General discussions of the principles and philosophy of radiation protection, and data and models for dose limits, can be found in the publications of the ICRP (International Commission on Radiological Protection) and the IAEA (International Atomic Energy Agency).

8.1 SA LEGISLATION

- Radiation Protection and Control Act 1982
- Radiation Protection And Control (Ionising Radiation) Regulations 2000.
- Radiation Protection and Control (Transport of Radioactive Substances) Regulations 2003.

These can be downloaded from EPA legislation and regulations.

8.2 NATIONAL CODES AND STANDARDS PUBLISHED BY ARPANSA

Compliance with national codes and standards is often a condition of radiation licences and registrations in South Australia. These publications are available at ARPANSA Codes and Standards. They include the national Recommendations and Standards for limiting exposure to ionising radiation.

The more applicable publications include:

Recommendations for Limiting Exposure to Ionizing Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionizing Radiation (republished 2002)

Code of Practice for the Safe Transport of Radioactive Material (2008 Edition)

Safety Guide for the Safe Transport of Radioactive Material (2008 Edition)

Code of Practice and Safety Guide for Portable Density/Moisture Gauges Containing Radioactive Sources (2004)

Code of Practice for the Exposure of Humans to Ionizing Radiation for Research Purposes (2005)

Code of Practice for the Security of Radioactive Sources (2007)

Code of practice for protection against ionizing radiation emitted from X-ray analysis equipment (1984) [currently under review]

Code of practice for the disposal of radioactive wastes by the user (1985) [currently under review]

Recommended limits on radioactive contamination on surfaces in laboratories (1995)

8.3 AUSTRALIAN STANDARDS

Australian Standard AS 2243.4—1998, Safety in laboratories, Part 4: Ionizing radiations.

Downloadable from UniSA Australian Standards on-line subscription .

8.4 BOOKS

Alan Martin & Samuel A. Harbison, An Introduction to Radiation Protection, Chapman & Hall, Fifth Edition, 2006

Daniel A. Gollnick, Basic Radiation Protection Technology, 4^{th} edition, Pacific Radiation Corp, 2000.

H. Cember, Introduction to Health Physics, 3^{rd} edition, Permagon Press, 1996.

CCH Australia, Laboratory Safety Manual, chapter on radiation safety