



THE UNIVERSITY OF  
MELBOURNE



# Ionising Radiation Management Guidelines



### **About this Guide**

The *Ionising radiation management guidelines* have been developed to support the [Health & Safety: Ionising radiation requirements](#)

The authors have made every effort to confirm the accuracy and validity of material presented in this document. The authors will take no responsibility for how the material in these guidelines is used.

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# 1 INTRODUCTION

## 1.1 Management guidelines

The *Ionising radiation management guidelines* will assist staff and students to safely undertake work and activities using ionising radiation. The guidelines provide background information and guidance on the safe use of ionising radiation at The University of Melbourne.

The *Ionising radiation management guidelines* is intended to be used in conjunction with University ionising radiation activities and in-house ionising training. See Section 11.1.2 for training information.

## 1.2 Brief history

Uranium was the first radioactive element to be discovered in 1789 by Martin Heinrich Klaproth. In 1896 more than 100 years after Klaproth's discovery, Antoine Becquerel identified its radioactive properties. One year prior to this (1895) Wilhelm Röntgen<sup>1</sup> discovered the x-ray (Figure 1).

In the next three years, following Röntgen's discovery, Marie and Pierre Curie would discover polonium and radium. Within five years of Röntgen's discovery British doctors used a "mobile" x-ray machine to find bullets and shrapnel in wounded soldiers during the Sudan Campaign.



### X-Ray of Bertha Roentgen's hand

[Wilhelm Röntgen] convinced his wife to participate in an experiment. Röntgen placed her hand on a cassette loaded with a photographic plate. He then aimed the activated cathode ray tube at her hand for fifteen minutes. When the image was developed, the bones of her hand and the two rings she wore were clearly visible.

Horried at the result, Bertha Röntgen, like many to follow, saw in the image a premonition of death.

Today, an x-ray of the hand requires an exposure of about 0.02 to 0.04 of a second.

Figure 1: An x-ray of Bertha Röntgen's hand taken by Wilhelm Röntgen in 1895

In 1903 the Nobel Prize in Physics was divided, one half awarded to Antoine Henri Becquerel "in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity", the other half jointly to Pierre Curie and Marie Curie, "in recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel".

Figure 2 shows, from left to right, Henri Becquerel, Pierre Curie and Marie Curie.

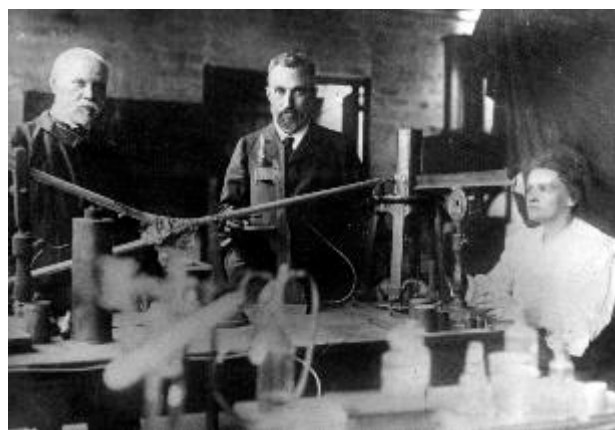


Figure 2: Henri Becquerel, Pierre and Marie Curie

<sup>1</sup> The English spelling of Röntgen is Roentgen.

The progression of both the discovery of radioactive elements and their uses continued well into the twentieth century. The timeline plotted by Bernier, Hall & Giaccia (2004) shows advances in radiation physics, radiobiology and radiotherapy from 1895 to 1950 (Figure 3).

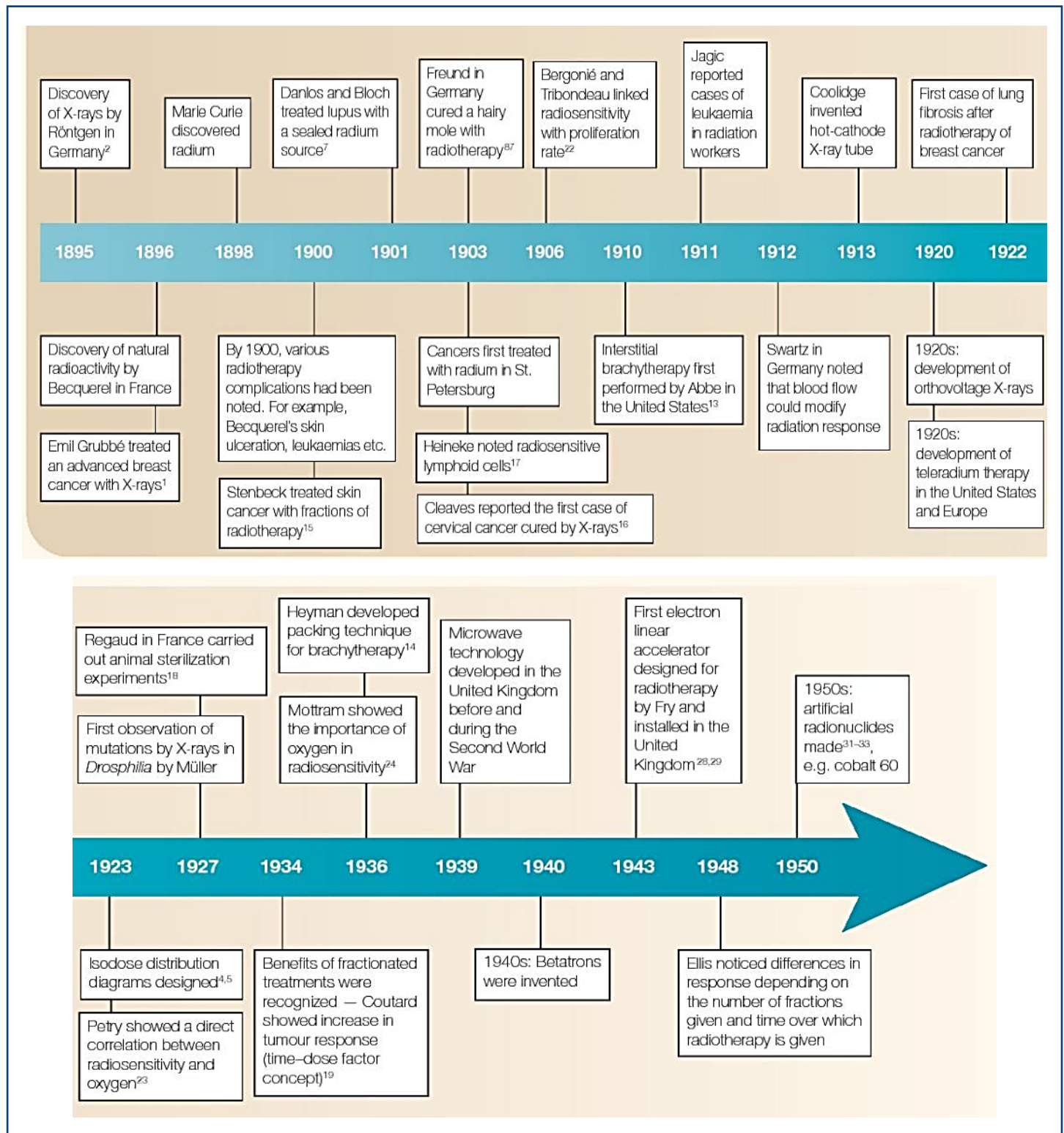


Figure 3: Time line – Advances in radiation physics, radiobiology and radiotherapy 1895 to 1950

### 1.3 Sourcing further information

Description of Information	Where to Obtain
British Institute of Radiology <ul style="list-style-type: none"><li>History of radiology</li></ul>	<a href="https://www.bir.org.uk/useful-information/history-of-radiology.aspx">https://www.bir.org.uk/useful-information/history-of-radiology.aspx</a>

### 1.4 References

Bernier J, Hall E J & Giaccia A, 2004. 'Radiation oncology: a century of achievements', *Nature Reviews. Cancer*, vol 4, issue 9, pp 737-747.

## 2 LEGAL REQUIREMENTS

Acts, Regulations, Standards and Codes oversee the administration and control of radiation sources. Regulatory control is governed by both Commonwealth and State. Therefore, several Government authorities may be responsible for the oversight and administration of different radiation activities.

### 2.1 Commonwealth

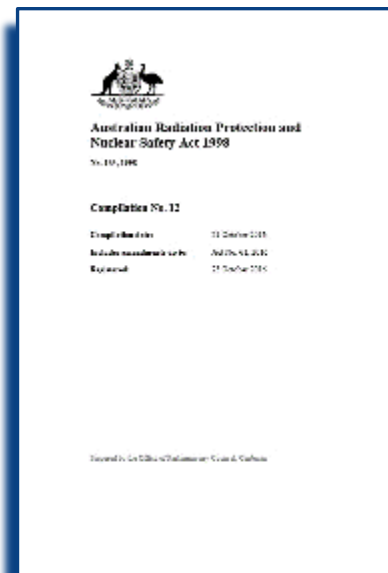
Commonwealth radiation legislation is administered by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and includes:

- *Australian Radiation Protection and Nuclear Safety Act 1998 (Cth)*; and
- *Australian Radiation Protection and Nuclear Safety Regulations 2018 (Cth)*.

Additional Commonwealth legislation has radiological requirements. For example, the Australian Safeguards and Non-Proliferation Office (ASNO) administers the following:

- *Nuclear Non-Proliferation (Safeguards) Act 1987 (Cth)*.

The *Nuclear Non-Proliferation (Safeguards) Act 1987 (Cth)* has specific storage, security and reporting requirements for named radiation sources that have been identified as possible uncontrolled use in the proliferation of nuclear weapons.



### 2.2 State

#### 2.2.1 Introduction

Victorian radiation legislation is administered by the Department of Health (DH) and includes:

- *Radiation Act 2005 (Vic)*; and
- *Radiation Regulations 2017 (Vic)*.

State legislation controls the possession, sale and use of radiation sources in Victoria. The legislation mandates:

- radiation protection principles (Section 6.1);
- radiation dose limits (Section 2.2.4); and
- licensing requirements (Section 2.2.5, Section 2.2.6 and Section 2.2.7).

Radiation legislation also requires:

- people working with radiation sources be individually licensed (*use licence*) – there may be exemptions granted under certain conditions;
- people working with radiation sources be appropriately trained to the nature of tasks undertaken; and
- workplaces with radiation sources comply with the applicable legislative requirements.



## 2.2.2 Radiation source

The *Radiation Act 2005* (Vic) defines a radiation source to mean:

- **radioactive material;**  
Radioactive material spontaneously emits radiation and is normally described as an open or closed source.
- **radiation apparatus;** or  
Radiation apparatus produces radiation when activated, such as an x-ray machine.
- **sealed source apparatus.**  
Sealed source apparatus contains radioactive material that is fully encapsulated, such as a soil moisture/density probe.

### Day-to-day practical application of radiation sources

The different categories of radiation sources each have their own advantages, disadvantages and usages. For example, some open sources have a long half-life which can result in potential radiological wastes that cannot be disposed of through normal waste streams.

	Open Sources	Closed Sources	Ionising Radiation Apparatus
Examples	$^3\text{H}$ , $^{14}\text{C}$ , $^{35}\text{S}$ , $^{32}\text{P}$ , $^{33}\text{P}$ , $^{125}\text{I}$	$^{60}\text{Co}$ , $^{137}\text{Cs}$ , $^{68}\text{Ge}$	X-ray machines, Linear accelerators, Cyclotrons, Fluoroscopy
Advantages	<ul style="list-style-type: none"><li>• Used in small quantities</li><li>• Easy to shield</li></ul>	<ul style="list-style-type: none"><li>• No Internal contamination</li></ul>	<ul style="list-style-type: none"><li>• No Half-life concerns</li><li>• No Waste disposal problems</li></ul>
Disadvantages	<ul style="list-style-type: none"><li>• Half life</li><li>• Spills</li><li>• Internal contamination</li><li>• Waste disposal</li></ul>	<ul style="list-style-type: none"><li>• Potential Large Dose</li><li>• Half life</li><li>• Shielding</li><li>• Security</li></ul>	<ul style="list-style-type: none"><li>• Potential Large Dose</li><li>• Shielding</li><li>• Security</li></ul>
Common Use	<ul style="list-style-type: none"><li>• Biological areas</li><li>• Medical research</li></ul>	<ul style="list-style-type: none"><li>• Physical Sciences</li><li>• Industrial areas</li></ul>	<ul style="list-style-type: none"><li>• Medical research</li><li>• Physical Sciences</li></ul>

## 2.2.3 Legal definition of radioactive material

The *Radiation Regulations 2017* (Vic) defines radioactive material as follows.

For the purposes of paragraphs (a) and (b)(i) of the definition of radioactive material in section 3(1) of the Act—

- a the prescribed activity concentration for a material that is a radionuclide specified in Column 1 of Schedule 1 is the activity concentration specified in Column 2 of that Schedule opposite that radionuclide; and
- b the prescribed activity for a material that is a radionuclide specified in Column 1 of Schedule 1 is the activity specified in Column 3 of that Schedule opposite that radionuclide.

### Legal definition of radioactive material simplified

The *Radiation Regulations 2017* (Vic) lists all radioactive materials in Schedule 1, “Activity Concentrations and Activities of Radionuclides”.

The Schedule considers both “activity concentration” and the “activities” of each radionuclide listed.



## 2.2.4 Ionising radiation dose limits

Dose limits refer to the maximum amount (dose) of ionising radiation that a person can be exposed to. In Victoria, these limits are regulated by the *Radiation Regulations 2017* (Vic) – Schedule 4.

The dose limits are categorised as occupational or public (Table 1). An occupational dose limit applies to people working with ionising radiation.

Ionising radiation dose limits for occupational exposure	
<i>Circumstance</i>	<i>Dose limit</i>
Receipt of ionising radiation doses in any 60 month period	Effective dose of 100 millisievert
Receipt of ionising radiation doses in any 12 month period	Effective dose of 50 millisievert
Receipt of ionising radiation to the lens of an eye of a person in any 60 month period	Equivalent dose of 100 millisievert
Receipt of ionising radiation to the lens of an eye of a person in any 12 month period	Equivalent dose of 50 millisievert
Receipt of ionising radiation to the skin of a person in any 12 month period	Equivalent dose of 500 millisievert averaged over 1 cm <sup>2</sup> of any part of the skin regardless of the total area exposed
Receipt of ionising radiation to the hands and feet of a person in any 12 month period	Equivalent dose of 500 millisievert
Ionising radiation dose limits for public exposure	
<i>Circumstance</i>	<i>Dose limit</i>
Receipt of ionising radiation doses in any 12 month period	Effective dose of 1 millisievert
Receipt of ionising radiation to the lens of an eye of a person in any 12 month period	Equivalent dose of 15 millisievert
Receipt of ionising radiation to the skin of a person in any 12 month period	Equivalent dose of 50 millisievert averaged over 1 cm <sup>2</sup> of any part of the skin regardless of the total area exposed

Table 1: Ionising radiation dose limits

## 2.2.5 Licensing

The *Radiation Act 2005* (Vic) prescribes a licensing framework that regulates the conduct of radiation practices and the use of radiation sources in Victoria. This framework includes:

- *management licences*; and
- *use licences*.

## 2.2.6 Management licence

The *Radiation Act 2005* (Vic) requires a person or organisation to hold a *management licence* for the possession, sale, consignment or disposal of a radiation source. A licence must be held before the person or organisation conducts a radiation practice. The *management licence* is issued by the DH.

The *management licence* is held by a legal entity that is conducting the practice. Therefore, in most cases this will be an organisation/company rather than a person.

### Mandatory requirements

The DH has published information regarding the holder of a *management licence* [mandatory radiation safety requirements](#).

The mandatory requirements discussed include:

- radiation monitoring and dose assessment;
- storage of radioactive material;
- labelling and warning signs;
- radiation shielding;
- training;
- emergencies, accidents and incidents;
- ionising radiation management plan (recommended); and
- personal radiation monitoring.

### Schedules

The *management licence* is divided into “schedules” that distinguish radiation sources and their uses into 10 sections. Table 2 lists only those schedules applicable to the University’s *management licence*.

Schedule	Description
1	General Licence Conditions (including practice specific conditions)
2	Radiation Practices Involving Possession of Ionising Radiation Apparatus that are Prescribed Radiation Sources
3	Radiation Practices Involving Possession of Ionising Radiation Apparatus that are not Prescribed Radiation Sources
4	Radiation Practices Involving Sealed Source Apparatus
5	Radiation Practices Involving Sealed Sources
6	Radiation Practices Involving Unsealed Radioactive Material
8	Radiation Practices Not Involving Possession of Radiation Sources
9	Definitions
10	Offences

Table 2: Management licence schedules

## 2.2.7 Use licence

A person who uses a specified radiation source is required (unless exempted from that requirement) to hold a *use licence*. A *use licence* authorises the holder to use a specified type of radiation source for a specified purpose. The *use licence* is issued by the DH where the holder can demonstrate relevant prerequisites have been met for the radiation source being used.

Use licence requirements including exemptions and how they are applied to staff and students at the University are discussed in Section 3.2.4.

### 2.2.8 Ionising radiation research on participants (humans)

Ionising radiation research on humans is broadly categorised into two groups based on the dose constraints outlined in the *Code of Practice. Exposure of humans to ionizing radiation for research purposes RPS 8*<sup>2</sup>. Namely:

- the radiation dose to participants is **below the dose constraint**; or
- the radiation dose to participants is **above the dose constraint**.

If the dose of radiation is **below the dose constraint** and approval has been given by the University Human Research and Ethics Committee (HREC), notification to the DH is not required.

If the radiation dose is **above the dose constraint** and approval has been given by the HREC, then the University (the Researcher) must notify the DH. The project may commence prior to notification being submitted to the DH.

Researchers should refer to the DH web page [How to make an HREC application](#).

### 2.2.9 Certificate of compliance

The *Radiation Act 2005* (Vic) and the *Radiation Regulations 2017* (Vic) require that prescribed radiation sources must be issued with a certificate of compliance. These certificates can only be issued by a person approved by the DH as an approved tester.

Prescribed radiation sources are listed in Schedule 2 (see Table 2) of the *management licence*.

The scheduled date and frequency of the certificate of compliance testing is included with the prescribed radiation sources in the *management licence*.

The DH provides more information including contact details of [approved radiation testers](#):

## 2.3 State safety legislation

Victorian safety legislation is administered by WorkSafe and includes:

- *Occupational Health and Safety Act 2004* (Vic); and
- *Occupational Health and Safety Regulations 2017* (Vic).

Ionising radiation activities undertaken in the workplace must comply with the health and safety requirements mandated by occupational health and safety legislation.

The legislation requires the employer to:

- provide a safe and healthy environment for people working with radiation and others;
- maintain plant and equipment;
- maintain safe systems of work that ensure the safe use of hazardous substances and plant; and
- provide appropriate training, supervision and instruction.

The legislation requires the employee to cooperate with the employer with regards to safe systems of work.

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<sup>2</sup> Table 1 of the Code – Dose constraints for participants in research

## 2.4 Advisory bodies

### 2.4.1 Australian Radiation Protection and Nuclear Safety Agency

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is a Commonwealth Government Agency with numerous functions related to radiation protection and safety. With regards to the ionising radiation ARPANSA, develops and publishes national policies, codes and guides for consideration by the Commonwealth, States and Territories.

These publications, known as the [Radiation Protection Series](#) (RPS) are broadly categorised into three main areas:

1. Fundamentals
2. Codes and Standards
3. Guides and recommendations

#### Fundamentals

*Fundamentals for protection against ionising radiation (RPS F-1)*

This publication provides an understanding of the effects of ionising radiation and associated risks for the health of humans and of the environment. It further explains how radiation protection, safety and security can work individually and collectively to manage radiation risks. Finally, it presents ten principles and their application in management of radiation risks.

#### Codes and Standards

Codes and Standards that provide radiation users specific information and guidance on systems for minimising exposure to ionising radiation.

The Codes and Standards address specific radiological activities. For example:

- *Code of Practice: Exposure of humans to ionizing radiation for research purposes (RPS 8)*
- *Code of Practice & Safety Guide. Radiation protection in veterinary medicine (RPS 17)*

#### Guides and recommendations

These publications are designed to provide guidance on meeting the requirements and processes set out in the Codes and Standards.

For example, the *Guide for radiation protection in existing exposure situations (RPS G-2)* establishes a framework in Australia for the protection of occupationally exposed persons, the public and the environment in existing exposure situations. This guide applies a risk based approach when considering the application, justification and optimisation of existing exposure strategies and remedial actions.



## 2.4.2 International Commission on Radiological Protection

The International Commission on Radiological Protection (ICRP) develops and maintains the International System of Radiological Protection. This system is used world-wide as a common basis for radiological protection standards, legislation, guidelines, programmes, and practice.

## 2.4.3 International Atomic Energy Agency

The International Atomic Energy Agency (IAEA) serves as the world's central inter-governmental forum for scientific and technical cooperation in the nuclear field. It is a specialised agency within the United Nations.

## 2.4.4 Standards Australia

Standards Association of Australia define Standards as published documents setting out specifications and procedures designed to ensure products, services and systems are safe, reliable and consistently perform the way they were intended to. They establish a common language which defines quality and safety criteria.

Regarding ionising radiation, the relevant Australian Standard is AS 2243.4. *Safety in laboratories. Part 4. Ionizing radiations.*



## 2.5 Sourcing further information

Description of Information	Where to Obtain
Commonwealth legislation is available from: <ul style="list-style-type: none"><li>Federal Register of Legislation</li></ul>	<a href="https://www.legislation.gov.au/Home">https://www.legislation.gov.au/Home</a>
Victorian legislation is available from: <ul style="list-style-type: none"><li>Victorian Legislation</li></ul>	<a href="https://www.legislation.vic.gov.au/">https://www.legislation.vic.gov.au/</a>
DH radiation web site	<a href="https://www2.health.vic.gov.au/public-health/radiation">https://www2.health.vic.gov.au/public-health/radiation</a>
Approved radiation testers (DH)	<a href="https://licensing.dhhs.vic.gov.au/public/approved-tester">https://licensing.dhhs.vic.gov.au/public/approved-tester</a>
<i>Radiation management licences</i> (DH)	<a href="https://www2.health.vic.gov.au/public-health/radiation/licensing/management-licenses-businesses/general-conditions/acquisition-disposal-relocation">https://www2.health.vic.gov.au/public-health/radiation/licensing/management-licenses-businesses/general-conditions/acquisition-disposal-relocation</a>
<i>Radiation use licences</i>	<a href="https://www2.health.vic.gov.au/public-health/radiation/licensing/use-licences-employees">https://www2.health.vic.gov.au/public-health/radiation/licensing/use-licences-employees</a>
ARPANSA	<a href="http://www.arpansa.gov.au/">http://www.arpansa.gov.au/</a>
ARPANSA Radiation Protection Series	<a href="https://www.arpansa.gov.au/regulation-and-licensing/regulatory-publications/radiation-protection-series/codes-and-standards/rpsc-2">https://www.arpansa.gov.au/regulation-and-licensing/regulatory-publications/radiation-protection-series/codes-and-standards/rpsc-2</a>
Annals of the ICRP	<a href="http://www.icrp.org/publications.asp">http://www.icrp.org/publications.asp</a>
IAEA	<a href="https://www.iaea.org/">https://www.iaea.org/</a>



<p>Australian Standards (accessed via SAI Global)</p> <p>A University username and password is required.</p>	<ol style="list-style-type: none"> <li>1. Log-on to the University library</li> <li>2. You will need to search for SAI Global</li> </ol>
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## 3 UNIVERSITY REQUIREMENTS

To comply with the legal requirements outlined in the previous section the University has developed requirements, processes and guidance that consider both Commonwealth and State legislation. The requirements, processes and guidance also provide a safe and healthy environment for all staff and students working with radiation sources.

### 3.1 Policy and procedure

The University ionising radiation conditions and obligations are described in the:

- *Health & Safety: Ionising radiation requirements*; and
- *Health & Safety: Ionising radiation management plan*.

The Director, Health & Safety is responsible for developing, publishing and maintaining the requirements and the plan.

### 3.2 Licensing

#### 3.2.1 Management licence

The *management licence* is centrally controlled and maintained by the University Radiation Safety Advisor (RSA) on behalf of the Director, Health & Safety. This includes:

- maintaining a record of radiation sources used by the University; and
- providing the DH with mandated information where there are modifications to the current licence such as:
  - acquisition of radiation sources; and
  - disposal of radiation sources.

The University RSA provides each local area (radiation site) listed on the *management licence* the licensing conditions (practice specific conditions) relevant to their listed radiation sources and allowed practices.

It is the responsibility of the local area to:

- ensure systems are in place to meet the conditions of the *management licence*; and
- maintain an inventory of radiation sources (the local area management licence provided by the RSA can be used for this purpose).

#### 3.2.2 Varying the management licence

Varying the *management licence* will occur when a local area:

- intends to acquire a radiation source not listed at their location;
- intends to alter/modify a radiation source listed at their location;
- intends to relocate a radiation source to another location; or
- intends to dispose of a radiation source listed at their location.

It is the responsibility of the local area to provide this information to the University RSA prior to implementing changes.

[Health & Safety – Vary radiation management licences](#)

#### NOTE:

It is an offence under the *Radiation Act 2005* (Vic) for a local area to use a radiation source that is not listed against the relevant location on the University *management licence*.

### 3.2.3 Certificate of compliance

Local areas that have prescribed radiation sources listed at their location are responsible for:

- identifying and engaging an approved tester to ensure the prescribed radiation source has a certificate of compliance; and
- ensuring the certificate of compliance is in-date as outlined in the University *management licence*.

Refer to Section 2.2.9 for legal requirements and more information.

### 3.2.4 Use licence

All staff and student ionising radiation licensing requirements are maintained by the local area. Therefore, it is the local area's responsibility to:

- ensure staff and students have the appropriate training;
- ensure staff have a current *use licence* prior to using a radiation source;
- ensure that the *use licence* includes the proposed radiation source and activity; and
- maintain a current record of all staff *use licences*.

#### NOTE:

It is an offence under the *Radiation Act 2005 (Vic)* for a person to use a radiation source without a *use licence* (unless exempted) or in a manner that is not specified on their *use licence*.

Refer to [Mandatory radiation safety requirements for use licence holders \(Use Licence Condition\)](#) (DH) which outlines specified purposes and/or occupations and the specified types of radiation sources requiring a *use licence*.

A public register is also available of all *use licence* holders: [Radiation use licences public register](#)

### 3.2.5 Exemptions

The DH has gazetted [exemptions](#) for a person to hold a *use licence*. In most cases these exemptions include:

- staff/students who are training with regards to the radiation source or working towards a qualification where radiation sources will be used; or
- undergraduate and post graduate students where the course work or research involves the use of radiation sources.

Exemptions require both staff and students to be supervised by a person who has an appropriate *use licence*.

## 3.3 Responsibilities

### 3.3.1 Head of School/Division

The Head of School/Division shall allocate appropriate resources to ensure compliance to the *management licence* and conformance to University requirements.

### 3.3.2 Manager/supervisor

The manager/supervisor shall:

- comply with the conditions of the *management licence* and University requirements;
- implement the radiation protection principles (justification, optimisation and limitation);
- ensure all safety requirements are followed;
- ensure training is undertaken by to all staff and students prior to working with radiation sources;
- (where applicable) provide appropriate personal monitoring equipment to all staff and students;
- ensure all radiation monitoring equipment is maintained and calibrated;
- ensure all radiation sources are maintained as per the conditions of the *management licence*; and
- ensure records required by the relevant regulatory authorities are maintained and available.

### 3.3.3 University Radiation Safety Adviser

The University RSA shall:

- provide guidance to the Head of School/Division to appoint a Departmental Radiation Safety Officer (DRSO);
- provide advice on safe working practices, including storage, waste and transport;
- provide support to DRSOs;
- liaise with the relevant regulatory authorities;
- monitor and maintain the University *management licence*;
- undertake inspections, and provide recommendations to local areas;
- investigate and report “radiological incidents<sup>3</sup>” to the regulatory authority; and
- provide guidance on emergency procedures.

### 3.3.4 Departmental Radiation Safety Officer

The DRSO shall:

- liaise with the University RSA on local area radiation requirements;
- provide advice on safe working practices, including storage, waste and transport considering the *management licence* and University requirements;
- liaise with managers/supervisors;
- provide information to the University RSA on changes to local area radiation activities that may affect licensing;
- assisting managers/supervisors with ensuring that monitoring equipment is fit for purpose and calibrated;
- provide guidance on emergency procedures for possible radiological incidents;
- report radiological incidents to the University RSA; and
- maintain local area dose records.

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<sup>3</sup> Refer to Section 9.1 for an explanation of a radiological incident.



### 3.3.5 Staff and students

Staff and students shall:

- comply with local area instructions, such as risk assessments, standard operating procedures and emergency procedures;
- use personal monitoring devices where provided (see Section 8.1);
- report immediately to the supervisor/manager any instance of unsafe practice or hazard;
- understand the risks of the radiation sources being used;
- reduce to a minimum radiation risks in the workplace;
- comply with the conditions of the *management licence* and University requirements.

## 3.4 Electromagnetic Radiation Safety Committee

The Electromagnetic Radiation Safety Committee (ERSC) comprising twelve members and represents all areas of electromagnetic radiation; both ionising and non-ionising.

The ERSC is an advisory committee that provides guidance on the development and maintenance of electromagnetic radiation policy and procedures.

The Terms of Reference of the ERSC include:

- formulate, review and disseminate standards, rules and procedures relating to electromagnetic radiation that are to be carried out or complied with by all staff, contractors and others under the control of the University;
- formulate, review and disseminate training requirements relating to electromagnetic radiation;
- establish such specialist sub-committees as it may determine from time to time, to perform specific tasks on behalf of the Committee, the membership of which shall include at least one member of the Committee;
- meet at least three times per year;
- review and/or amend the Terms of Reference; and
- provide minutes to the Director, Health & Safety to be tabled at the University Health and Safety Committee.

## 3.5 University dose limits

University policy requires that ionising radiation activities, where reasonably practicable, undertaken at the University shall limit total whole body exposure to no more than that of a member of the public. These dose limits have been adopted to consider:

- pregnant staff or students; and
- students that may be under 18 years of age.

#### NOTE:

University effective dose limits are set to a whole body exposure of no more than that of a member of the public.

1 mSv annually

Refer to Table 1 (Section 2.2.4) that outlines the public dose limits defined in the *Radiation Regulations 2017* (Vic).

Ionising radiation activities that exceed the dose limits as set out in Table 1 are assessed by the University Radiation Safety Advisor (RSA). Advice and guidance shall be provided to reduce dose where reasonably practicable.

Adopting an effective dose limit that does not exceed public dose limits encourages best practice.

## 3.6 Sourcing further information

Description of Information	Where to Obtain
Victorian legislation is available from: <ul style="list-style-type: none"> <li>Victorian Legislation</li> </ul>	<a href="https://www.legislation.vic.gov.au/">https://www.legislation.vic.gov.au/</a>
University policy and requirements: <ul style="list-style-type: none"> <li><i>Health &amp; Safety: Ionising radiation requirements; and</i></li> <li><i>Health &amp; Safety: Ionising radiation management plan</i></li> </ul>	<a href="https://safety.unimelb.edu.au/safety-topics/radiation">https://safety.unimelb.edu.au/safety-topics/radiation</a>
University requirements for varying the management licence: <ul style="list-style-type: none"> <li><i>Health &amp; Safety – Vary radiation management licences</i></li> </ul>	<a href="https://au.promapp.com/unimelb/Process/Minimode/Permalink/D2WEmhA7wwOsrlroaRwMg">https://au.promapp.com/unimelb/Process/Minimode/Permalink/D2WEmhA7wwOsrlroaRwMg</a>
DH Radiation use licence public register	<a href="#">Radiation use licences public register</a>
<i>What do I need to include in my application for a licence – use? (DH)</i>	<a href="https://www2.health.vic.gov.au/about/publications/policiesandguidelines/guidance-and-policy-prerequisites-for-use-licences">https://www2.health.vic.gov.au/about/publications/policiesandguidelines/guidance-and-policy-prerequisites-for-use-licences</a>
Health & Safety team advice, information and guidance on ionising radiation practices at the University	<a href="https://safety.unimelb.edu.au/safety-topics/radiation">https://safety.unimelb.edu.au/safety-topics/radiation</a> <a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a>
Electromagnetic Radiation Safety Committee web page	<a href="https://safety.unimelb.edu.au/management/communication/committees/electromagnetic-radiation-safety-committee">https://safety.unimelb.edu.au/management/communication/committees/electromagnetic-radiation-safety-committee</a>
DRSO contacts <ul style="list-style-type: none"> <li>Access Business Partner Contacts</li> <li>Navigate to relevant Academic Division</li> </ul>	<a href="https://safety.unimelb.edu.au/people/community/local-contacts">https://safety.unimelb.edu.au/people/community/local-contacts</a>

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Victorian Government, 2017. *Radiation Regulations 2017*, Author, viewed 22 February 2021,

<<https://www.legislation.vic.gov.au/in-force/statutory-rules/radiation-regulations-2017/001>>.

## 4 IONISING RADIATION

### 4.1 The atom

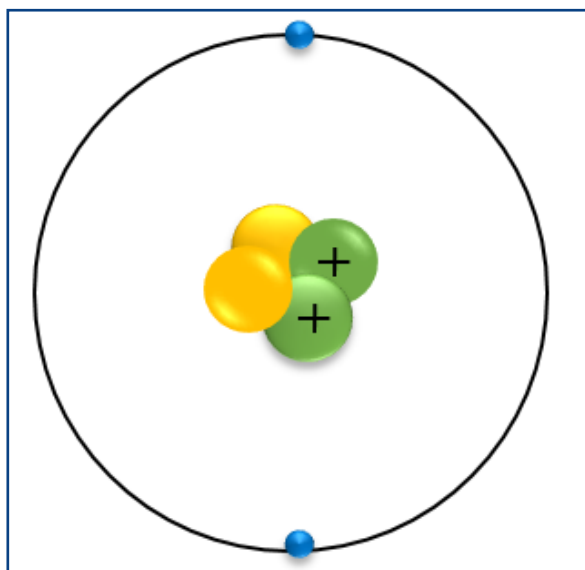





Figure 4: Atomic particles of the helium atom

The name "atom" is from the Greek word *atoms*, meaning "indivisible". An atom is the smallest unit of matter that is recognisable as a chemical element. In all ordinary processes, atoms can be considered the building blocks of matter.

Atoms are made up of three main particles (Figure 4):

-  protons;
-  neutrons; and
-  electrons.

Protons (which have a positive charge) and neutrons (which do not have a charge) form the nucleus of the atom. Electrons (which have a negative charge) orbit the nucleus.

Over 99.9% of the mass of an atom is made up of the nucleus, where protons and neutrons have a similar mass of  $1.6726 \times 10^{-27} \text{ kg}$  and  $1.6749 \times 10^{-27} \text{ kg}$  respectively. The electron has a mass approximately 1800 times smaller than protons and neutrons of  $9.11 \times 10^{-31} \text{ kg}$ .

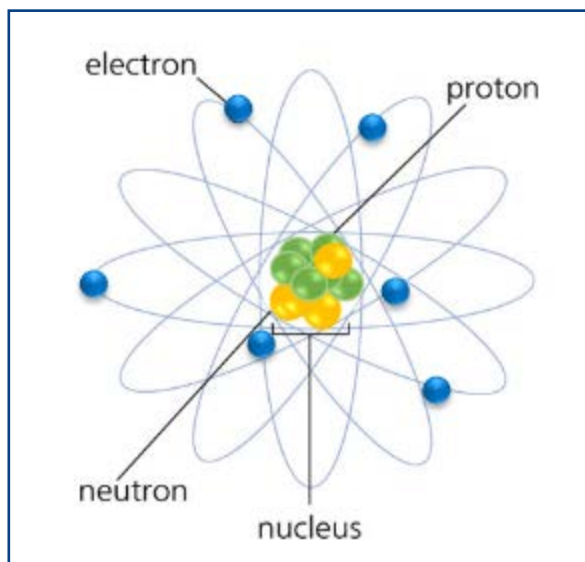


Figure 5: Atomic structure of a carbon atom

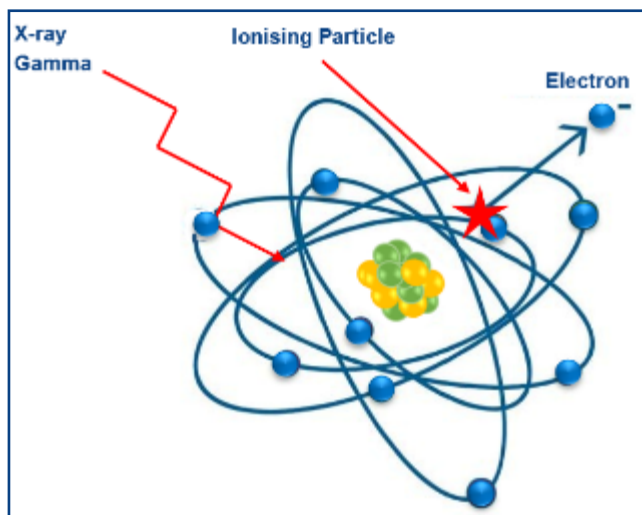
The size of a typical atom is about  $10^{-10}$  meters or an angstrom.

A cubic centimetre of solid matter contains approximately  $10^{24}$  atoms.

In 1913 Niels Bohr presented the "planetary model" (Figure 5) of the atom. He proposed that electrons can occupy only certain orbits at specific distances from the nucleus.

Bohr went on to explain that the electrons can jump from a low-energy orbit near the nucleus to orbits of higher energy by absorbing energy. When the electrons return to a lower energy level, they release the excess energy in the form of radiation.

## 4.2 Defining ionising radiation



Ionising radiation consists of highly energetic particles or electromagnetic waves that can detach electrons from atoms or molecules, thus ionising them (Figure 6).

Ionising radiation is the spontaneous emission of energy in the form of particles or waves (electromagnetic radiation), or both. These emissions are capable of producing changes in the atomic or nucleus structure which in simple terms means it modifies the basic building block of nature; the atom.

Figure 6: Representation of ionising radiation

## 4.3 Types of ionising radiation

Ionising radiation falls into two distinct categories:

- electromagnetic radiation; and
- particulate radiation.

### 4.3.1 Electromagnetic radiation

Electromagnetic radiation (EMR) is a wave-like energy that radiates through space. EMR has both electric and magnetic field components, which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation. The electromagnetic spectrum represents the entire range of frequencies of EMR (Figure 7).

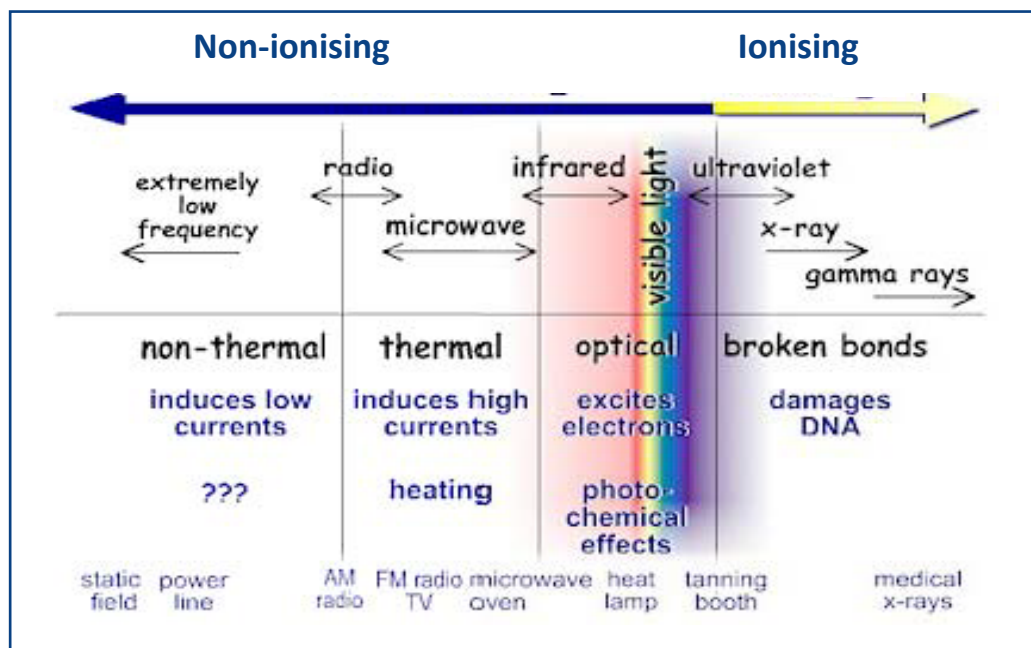


Figure 7: The electromagnetic spectrum (Study.com, 2017)



There are two types of EMR that are ionising. These are:

- x-rays; and
- gamma rays.

X-rays and gamma rays occur at the high end of the electromagnetic spectrum. This means that x-rays and gamma rays have a small wavelength and a large frequency, expressed in Hertz (Hz). For example, x-rays have a wavelength of approximately  $10^{-10}$  with a frequency of approximately  $10^{17}$  Hz. In comparison with low frequency radio waves that have a wavelength of  $10^5$  with a frequency of approximately  $10^3$  Hz.

### X-rays

X-rays are written as:  
**x-ray or X-ray**

X-rays are invisible; carry no charge and travel at the speed of light. Their wavelengths range from about 0.01 to 10 nanometres. X-rays overlap with the shorter-wavelength ultraviolet and longer-wavelength gamma ray portions of the electromagnetic spectrum. X-rays are produced when high-energy charged particles collide with other charged particles or atoms.

X-rays were discovered in 1895 by Wilhelm C. Röntgen.

### Gamma rays

Gamma-rays are  
symbolised by the  
Greek letter:  
 **$\gamma$**

Gamma rays, like x-rays, are invisible; carry no charge and travel at the speed of light<sup>4</sup>. Their wavelengths are generally shorter than x-rays having wave lengths less than 0.1 nanometres. The basic difference between the two is, gamma rays come from a nuclear process, whereas x-rays are atomic in origin.

Paul Villard discovered gamma rays in 1900. He detected gamma ray emissions from natural radioactive substances such as uranium, radium, and thorium.

## 4.3.2 Particulate radiation

Particulate radiation is produced by subatomic particles (protons, neutrons and electrons). Normally protons are not emitted alone but are combined with neutrons (Figure 8).

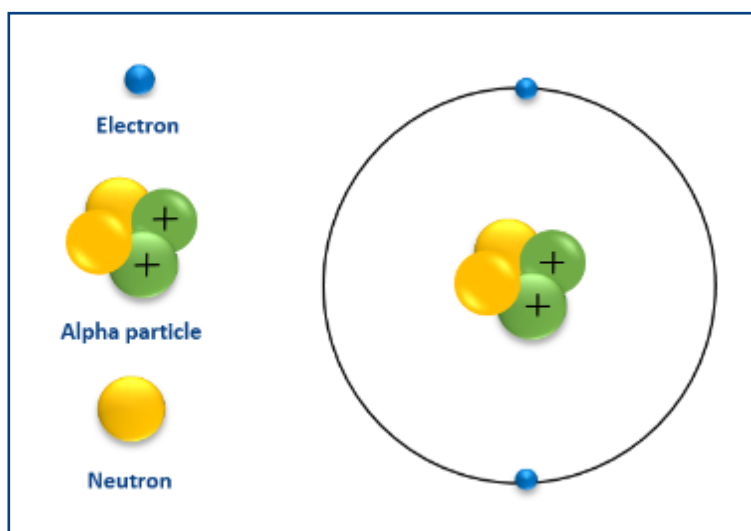


Figure 8: Particulate radiation

<sup>4</sup> The speed of light is 299,792,458 meters per second or 2.997925<sup>8</sup> m/s in a vacuum.

## Alpha particles

Alpha particles are symbolised by the Greek letter:  
 $\alpha$

Alpha particles are emitted from the nucleus of a radioactive atom. This is normally from heavy radioactive atomic nuclei during decay. Alpha particles are a stable combination of two protons and two neutrons. The energy range is approximately 4 MeV to 11 MeV.

The proton was the second subatomic particle to be identified by Rutherford in 1919. He discovered the proton as a product of the disintegration of the atomic nucleus.

## Beta particles

Beta particles are symbolised by the Greek letter:  
 $\beta$

Beta particles are electrons that are negatively or positively charged (positron). Electrons are fundamental particles or leptons<sup>5</sup> in that they are not composed of simpler particles in the way that, for example, protons are composed of quarks. Their maximum energy normally varies from 0.01 MeV to 3 MeV depending on the beta emitter.

The electron was the first subatomic particle discovered by Joseph John Thomson in 1897.

## Neutrons

Neutron particles are symbolised by the letter:  
 $n$

Neutron particles are released when a radioactive atom disintegrates. They are uncharged nuclear particles classified depending upon their energy into two major groups, either thermal neutrons (slow neutrons) or fast neutrons. Thermal neutrons have an energy range of less than or equal to 0.04 eV. Fast neutron energies are greater than 1 MeV or approximately 1 MeV, depending on the definition.

The neutron was discovered by James Chadwick in 1932.

## 4.4 Penetration properties

The penetrating properties (Figure 9) of the ionising radiation are dependent on the:

- type of radiation;
- activity of the source; and
- level of energy.

### 4.4.1 Penetration properties and the type of radiation

#### Alpha radiation



Alpha particles are highly charged and will quickly ionise with whatever they encounter. This means that their penetrating properties are very low. For example, alpha particles will only travel a few centimetres in air.

#### Beta radiation



Beta particles are not as highly charged as alpha particles. This means that they can penetrate a longer distance before ionising.

#### Neutron radiation



Neutrons, like x-rays and gamma rays do not have a charge and therefore they do not interact readily with surrounding matter. This means they can also travel/penetrate appreciable distances.

<sup>5</sup> A lepton is a class of fundamental particles that includes electrons, neutrinos, muons, and their antiparticles. The name is derived from the Greek word meaning lightweight.

## X-Ray and gamma ray

X-ray radiation and gamma ray radiation have no charge and therefore will penetrate greater distances than beta radiation. This property makes x-rays a useful diagnostic tool because the x-ray will go straight through the body and ionise very few cells.

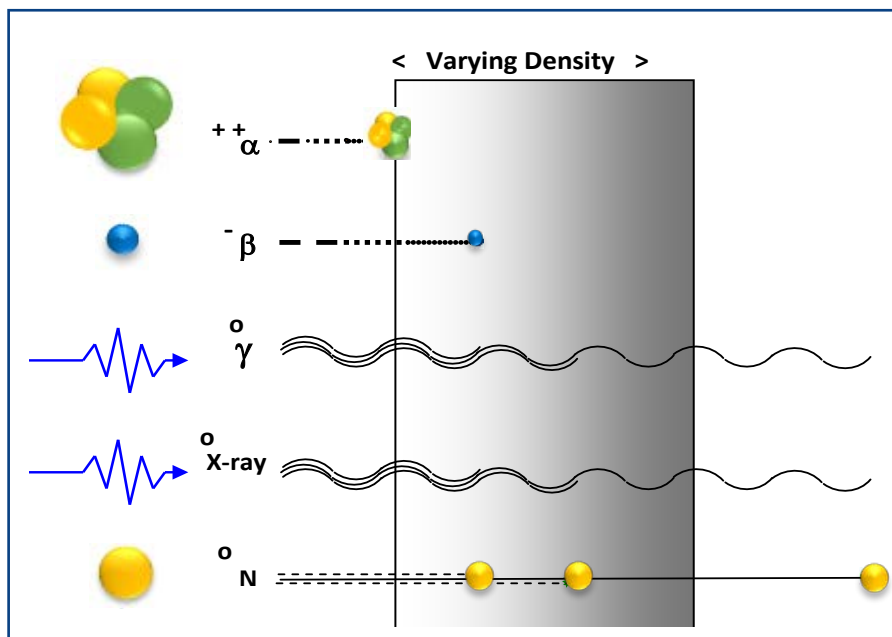


Figure 9: Penetrating properties of ionising radiation

### 4.4.2 Penetration properties and the activity of the source

Activity is defined as the number of atoms in a radiation source disintegrating over time. This is explained in more detail in Section 4.8.1.

The greater/higher the activity of the radiation source, the more penetrating it will be.

### 4.4.3 Penetration properties and the level of energy

The level of energy is determined by the kinetic energy gained by an electron passing through a potential difference of one volt in a vacuum. This is explained in more detail in Section 4.8.2.

The greater/higher the energy of the radiation source, the more penetrating it will be.

### 4.4.4 Summary of penetrating properties

In summary, various properties of the different types of ionising radiation can be compared (Table 3).

Type of Radiation	Symbol	Electrical Charge	Penetration	Ionising Strength
alpha (helium nuclei)	$\alpha$	++ charge	short	strong
beta (electrons)	$\beta$	- charge	moderate	moderate
neutron (neutrons)	n	no charge	short to high	weak to strong
Gamma	$\gamma$	no charge	high	weak
X-ray	X	no charge	high	weak

Table 3: Summary of properties of ionising radiation

## 4.5 Radioactive isotope

Radioactive isotopes can be defined as two or more atoms that have the same atomic number but have different mass numbers. The atomic number represents the number of protons in an atom. The nuclear number (mass number) represents the number of protons and neutrons in an atom. Therefore, radioactive isotopes for a given atom will have the same number of protons, but a different number of neutrons.

### Example

Compare three radioactive isotopes for cobalt (Co):  $^{57}\text{Co}$ ,  $^{58}\text{Co}$  and  $^{60}\text{Co}$ .

Each isotope has the same number of protons – in this case 27 – but has a different number of neutrons.

- $^{57}\text{Co}$  – 30 neutrons
- $^{58}\text{Co}$  – 31 neutrons
- $^{60}\text{Co}$  – 33 neutrons

Further examples of radioactive isotopes are listed in Appendix A: Properties of Some Commonly Used Radionuclides (Standards Association of Australia, 1998<sup>6</sup>).

[Ptable](#) is a useful interactive periodic table that describes the physical properties of radiological isotopes:

## 4.6 International System of Units

The International System of Units also referred to as SI Units; from the French *Système Internationale D'Unités*. The International System of Units specifies a set of unit prefixes known as SI prefixes. An SI prefix is a descriptor that precedes a basic unit of measure to indicate a decadic<sup>7</sup> multiple or fraction of the unit. There are twenty SI prefixes, each with a unique symbol, ranging from Y (yotta;  $10^{24}$ ) to y (yocto;  $10^{-24}$ ).

SI prefixes are used to reduce the number of zeros shown in numerical quantities before or after a decimal point. For example, 0.000000001 becquerel (Bq), is written by using the SI prefix “nano”. This is 1 nano becquerel or 1 nBq.

Units used in ionising radiation vary greatly from extremely large to extremely small. SI units provide a convenient method to quantify these units (Table 4). There is a preference to use only a small number of SI prefixes when quantifying the amount and describing the properties of ionising radiation as follows:

- T (tera;  $10^{12}$ )
- G (giga;  $10^9$ );
- M (mega;  $10^6$ );
- m (milli;  $10^{-3}$ ); and
- $\mu$  (micro;  $10^{-6}$ ).

<sup>6</sup> The current 2018 version of AS 2243.4:2018 Safety in laboratories. Part 4. Ionizing radiations does not include the examples of radioactive isotopes.

<sup>7</sup> In mathematics, decadic refers to the logarithmic scale to the base ten.

Prefix	Symbol	$10^n$	Decimal
peta	P	$10^{15}$	1,000,000,000,000,000
tera	T	$10^{12}$	1,000,000,000,000
giga	G	$10^9$	1,000,000,000
mega	M	$10^6$	1,000,000
kilo	k	$10^3$	1,000
		$10^0$	1
milli	m	$10^{-3}$	0.001
micro	$\mu$	$10^{-6}$	0.000001
nano	n	$10^{-9}$	0.000000001
pico	p	$10^{-12}$	0.000000000001

Table 4: SI prefixes commonly used in ionising radiation

## 4.7 Atomic nomenclature

The correct nomenclature (system of symbols and numbers) for writing radioactive isotopes is to place the atomic mass (the number) first in superscript, followed by the element's symbol. Using Uranium-238 as an example the correct nomenclature would be  $^{238}\text{U}$ .

Nevertheless, it is usual to see radioactive isotopes written differently. Continuing with Uranium-238 as the example, the following variations are also commonly written:

- 238U;
- 238-U
- U238; and
- U-238.

## 4.8 Measuring radiation

### 4.8.1 Activity

Activity defines how many atoms in a radiation source are disintegrating over time.

The unit of measurement of activity is the:  
**becquerel (Bq)**

A becquerel<sup>8</sup> is defined as:

- one disintegration per second (1 Bq = 1 dps); or
- 60 counts per minute (60 cpm).

In Australia radioactivity is expressed in becquerels, however units can still be expressed in curie (Ci), particularly where the radioactive material has originated from overseas. Therefore, it is useful to know the conversion of curie to becquerel (Table 5).

#### Curie to becquerel conversion

$$1 \text{ Ci} = 37 \times 10^9 \text{ or } 3.7 \times 10^{10}$$

<sup>8</sup> In 1975 the becquerel replaced the curie (Ci) as the SI unit of radioactivity.

Curie Ci	Becquerel Bq	dps	cpm
1	$37 \times 10^9 (3.7 \times 10^{10})$	$37 \times 10^9 (3.7 \times 10^{10})$	$2.22 \times 10^{12}$
0.1 (100 mCi)	$3.7 \times 10^9$	$3.7 \times 10^9$	$2.22 \times 10^{11}$
0.01 (10 mCi)	$3.7 \times 10^8$	$3.7 \times 10^8$	$2.22 \times 10^{10}$
0.001 (1 mCi)	$3.7 \times 10^7$	$3.7 \times 10^7$	$2.22 \times 10^9$
0.0001(100 µCi)	$3.7 \times 10^6$	$3.7 \times 10^6$	$2.22 \times 10^8$

Table 5: Conversion of curie to becquerel

Most isotopes used in biomedical research are expressed in kilo becquerel (kBq) or mega becquerel (MBq) of activity.

### Everyday radiological activity

The question can be asked. “I know what a becquerel is, but how much is too much?”

To answer the question Table 6 provides a comparison of the radiological activities of different substances in the everyday environment.

Substance	Becquerel (Bq)
1 kg of granite	1000
1 kg of coffee	1000
1 kg coal ash	2000
100 m <sup>2</sup> of air in an Australian home (radon)	3000
1 kg super phosphate fertiliser	5000
1 adult human	7000
100 m <sup>2</sup> of air in a European home	30,000
1 household smoke detector	30,000
1 kg uranium ore (Australian, 0.3%)	500,000
1 kg low level radioactive waste	1 million
1 kg uranium	25 million
1 radioisotope source for medical diagnosis	70 million
1 luminous exit sign (1970s)	1,000,000 million
1 kg 50-year old vitrified high-level nuclear waste	10,000,000 million
1 radioisotope source for medical therapy	100,000,000 million

Table 6: Examples of radiological activity in the everyday environment

## 4.8.2 Electron volt

The unit of measurement of ionising radiation energy is the:  
**electron volt (eV)**

An electron volt is the kinetic energy gained by an electron passing through a potential difference of one volt in a vacuum. In other words, a unit of energy equal to the energy an electron gains by being accelerated across an electric potential of 1 volt in a vacuum.

This can be expressed as one volt (or one joule per coulomb) multiplied by an electron charge (Figure 10).

Electron volts are normally expressed in keV (thousand electron volts) or MeV (million electron volts).

Energy is normally expressed by the SI unit joule (J). However, this unit is too large to quantify ionising radiation energy in a health and safety application. The electron volt is therefore used for this purpose.

One electron volt is equal to  $1.60217648 \times 10^{-19}$  joule (J).



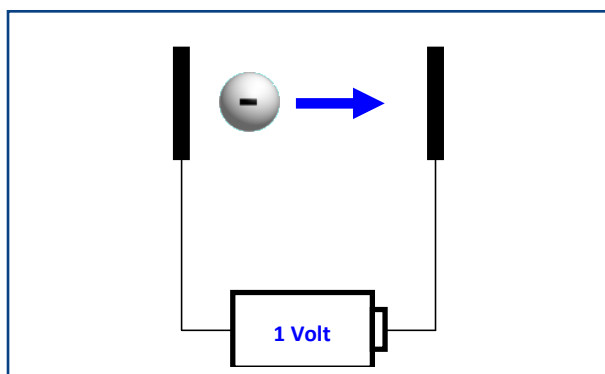


Figure 10: 1 volt in a vacuum

### 4.8.3 Radiological energy

Radiological energy is a term used to quantify exposure levels. As all isotopes are different it becomes apparent that the absorbed energy in biological tissue from any isotope is dependent on the amount of energy absorbed. Therefore, the time of exposure and rate of exposure must be defined.

The roentgen (R) is a unit of measurement for exposure to ionising radiation for x-rays and gamma rays. It is named after the German physicist Wilhelm Röntgen (Section 1.2).

The roentgen (R) is defined as the quantity of gamma ray or x-ray radiation required to produce one electrostatic unit of electricity (either positive or negative) per cubic centimetre of dry air. Radiological energy is only valid for x-ray or gamma ray interaction with air. It does not relate to tissue absorption or particulate radiation.

Normally, exposure is expressed in roentgens/hour or milliroentgens/hour (R/h or mR/h respectively).

Exposure is based upon the ionisation of a mass of air because of the relative ease with which it can be measured. Knowing that the average energy dissipated in the production of a single ion pair in air is 34 eV the absorbed air dose can then be calculated.

### 4.8.4 Absorbed dose

The unit of measurement of absorbed dose is the:  
**gray (Gy)**

Absorbed dose will be the amount of energy deposited into a material by ionising radiation. It only measures the quantity of energy that is deposited in a material it does not measure the effect of that energy on the material.

The absorbed dose is defined by the ratio of released (absorbed) energy over the mass of the matter.

A gray corresponds to one joule of energy released in one kilogram of matter. This can be written as:

$$1 \text{ Gy} = 1.0 \text{ J/kg}$$

### 4.8.5 Equivalent dose

The unit of measurement of equivalent dose is the:  
**sievert (Sv)**

The equivalent dose evaluates the likelihood of harm from the absorbed dose on biological tissues (humans).

Additionally, different types of radiations cause varying degrees of damage on biological tissue. Therefore, a radiation weighting factor ( $W_R$ ) is considered for both the type and the energy of the radiation (Table 7).

The radiation weighting factor is also referred to as the radiation quality factor.

Particle/Photon	Radiation Weighting Factor
Neutrons < 10 keV	5
Neutrons 10 keV – 100 keV	10
Neutrons 100 keV – 2 MeV	20
Neutrons 2 MeV – 20 MeV	10
Neutrons > 20 MeV	5
Alpha Particles	20
Beta Particles	1
X – Rays	1
Gamma Rays	1
Protons	0.5

Table 7: The radiation weighting factors for different types of ionising radiation

The equivalent dose is determined by the following equation:

$$H = D \times W_R$$

**H** = equivalent dose      **D** = average absorbed dose in the organ      **W<sub>R</sub>** = radiation weighting factor

#### Example

Compare 50 mg of fast neutrons (100 keV – 2 MeV) and 50 mGy of gamma radiation when absorbed by a biological system. What is the equivalent dose of each?

Therefore:

Fast neutrons (100 keV – 2 MeV):  $H = 50 \times 10^{-3} \times 20 = 1000 \times 10^{-3} = 1 \text{ Sv}$

Gamma radiation:  $H = 50 \times 10^{-3} \times 1 = 50 \times 10^{-3} = 0.05 \text{ Sv}$

### 4.8.6 Banana equivalent dose

Another way of considering equivalent dose is to look at naturally occurring levels of radiation in food.

Bananas contain a natural source of radiation <sup>40</sup>K (potassium – 40). The activity of one banana is approximately 0.1 µSv.

The banana equivalent dose (BED) is an informal measurement of ionising radiation exposure. It's intended as a general example to compare a dose of radioactivity to the dose one is exposed to by eating a banana (Table 8).

Number of bananas	Equivalent exposure
100,000,000	Fatal dose (death within 2 weeks)
20,000,000	Typical targeted dose used in radiotherapy (one session)
70,000	Chest CT scan
20,000	Mammogram (single exposure)
1,500	Average annual background exposure in Australia
1,000	Chest x-ray (average adult exposure)
700	Living in a brick building for one year
110	Return flight from Melbourne to London
50	Dental x-ray

Table 8: Banana equivalent dose



## 4.8.7 Effective dose

The unit of measurement of effective dose is the: **sievert (Sv)**

Different organs/tissues in the human body will have varying degrees of sensitivity to ionising radiation. Effective dose measures the harmful effects of ionising radiation on individual exposed organs and tissues.

Effective dose is the product of the equivalent dose (H) measured in Sv in a tissue or organ and the tissue weighting factor ( $W_T$ ), summed over all the affected areas of the body. The whole body effective dose is equal to one.

The effective dose is determined by the following equation:

$$E = H \times W_T$$

**E** = effective dose      **H** = equivalent dose       **$W_T$**  = tissue weighting factor

### Example

The lungs receive 2 mSv of equivalent dose ( $W_T = 0.12$ ) and the thyroid receives 1 mSv equivalent dose ( $W_T = 0.04$ ). What is the effective dose?

Therefore:

For the lungs:  $E = 2 \times 0.12 = 0.24$  mSv

### A confusion with SI units

Effective dose, (expressed in Sv) is a means of assigning probable biological risk to humans. As can be seen equivalent dose and effective dose both use the sievert as their unit.

When you read Sv (unless stated) assume it to mean effective dose.

The Commonwealth Government has adopted the tissue weighting factors from the ICRP Publication 103<sup>9</sup> (Table 9).

Tissue Weighting Factors	
Organs and Tissues	$W_T$
bone marrow (red), colon, lungs, stomach, breast, remaining tissues*	0.12
gonads	0.08
bladder, oesophagus, liver, thyroid	0.04
bone surfaces, brain, salivary glands, skin	0.01
* adrenals, extrathoracic (et) region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (♂), small intestine, spleen, thymus, uterus/cervix (♀)	0.12
<b>whole body</b>	<b>1</b>

Table 9: Tissue weighting factors

<sup>9</sup> The 2007 recommendations of the International Commission on radiological protection

## 4.8.8 Dose rate

The unit of measurement of dose rate is the:

**sievert (Sv) per unit of time**

Dose rate is the amount of radiation that is received over a specified time.

When detected with a portable Geiger counter it is normally expressed in sievert per hour.

### Example

When working for 2 hours with 2 mSv/h of activity the dose is:

$$2 \times 2 \times 10^{-3} = 4 \text{ mSv}$$

## 4.8.9 Summary of radiation units

Radiation SI units can be summarised and compared to the old radiation units (Table 10).

Type	SI Unit	Symbol	Old Unit	Symbol	Conversion
exposure (photons only)	coulomb per kilogram	C/kg	roentgen	R	1C/kg = 3876 R
absorbed dose	gray	Gy	rad	r	1Gy = 100 r
equivalent dose	sievert	Sv	rem <sup>10</sup>	rem	1Sv = 100 rem
effective dose	sievert	Sv	rem	rem	1Sv = 100 rem
dose rate	sievert per hour	Sv/h	rem per hour	rem/h	1Sv/h = 100 rem/h

Table 10: Summary and comparison of radiation SI units with the old radiation units

## 4.9 Radioactive decay

### 4.9.1 Defining radioactive decay

Radioactive decay is the process where an isotope with an unstable nucleus undergoes spontaneous transformation resulting in new elements and/or isotopes with emissions of ionising radiation.

For example, <sup>238</sup>U (Uranium 238) has an unstable nucleus. Due to radioactive decay <sup>238</sup>U changes through many different isotopes until it finally becomes the stable element of lead (Figure 11).

The new isotopes formed (because of radioactive decay) are referred to as progeny or daughter products.

The amount of decay of any radioactive isotope is time dependent and this dependency is directly proportional to its half-life.

<sup>10</sup> Rem stands for roentgen equivalent man.
















Uranium 238 ( $^{238}\text{U}$ ) Radioactive Decay				
		Nuclide		Half-life
		uranium-238	$^{238}\text{U}$	$4.5 \times 10^9$ years
$\alpha$	↓			
		thorium-234	$^{234}\text{Th}$	24.5 days
$\beta$	↓			
		protactinium-234	$^{234}\text{Pr}$	1.14 minutes
$\beta$	↓			
		uranium-234	$^{234}\text{U}$	$2.33 \times 10^5$ years
$\alpha$	↓			
		thorium-230	$^{230}\text{Th}$	$8.3 \times 10^4$ years
$\alpha$	↓			
		radium-226	$^{226}\text{Ra}$	$1.59 \times 10^3$ years
$\alpha$	↓			
		radon-222	$^{222}\text{Rn}$	3.825 days
$\alpha$	↓			
		polonium-218	$^{218}\text{Po}$	3.05 minutes
$\alpha$	↓			
		lead-214	$^{214}\text{Pb}$	26.8 minutes
$\beta$	↓			
		bismuth-214	$^{214}\text{Bi}$	19.7 minutes
$\beta$	↓			
		polonium-214	$^{214}\text{Po}$	$1.5 \times 10^{-4}$ seconds
$\alpha$	↓			
		lead-210	$^{210}\text{Pb}$	22 years
$\beta$	↓			
		bismuth-210	$^{210}\text{Bi}$	5 days
$\beta$	↓			
		polonium-210	$^{210}\text{Po}$	140 days
$\alpha$	↓			
		lead-206	$^{206}\text{Pb}$	stable

Figure 11: The radioactive decay of  $^{238}\text{U}$

#### 4.9.2 Radioactive half-life

Radiological half-life is the time required for a radionuclide, or radioactive isotope, to decay to one-half its original activity. After one half-life, only 50% of the original radioisotope activity remains. After two half-lives, only 25% remains and so on. The decay process converts the original isotope to a new element, as described in the example for Uranium 238 in Figure 11.

##### Example

$^{226}\text{Ra}$  (Radium-226), has a half-life of 1,620 years. An elapsed time of 1,620 years would result in one-half of the original  $^{226}\text{Ra}$  being converted to  $^{222}\text{Rn}$  (Radon-222) through alpha emission.

Each radioactive isotope has its own unique half-life. These can vary from fractions of a second to several billion years. For example, compare two uranium isotopes  $^{219}\text{U}$  and  $^{238}\text{U}$ . The half-life of  $^{219}\text{U}$  is 55  $\mu$  seconds and the half-life of  $^{238}\text{U}$  is 4,471,000,000 years.

The half-life of a radioactive isotope is independent on:

- the physical state (solid, liquid, gas);
- the temperature;
- the pressure; and
- the chemical compound.

### Half-life calculations

If the activity and half-life of a radioactive isotope is known at a given point in time (Figure 12), then its activity can be calculated at another point in time. The equation is:

$$A_t = A_0 / 2^n$$

$A_t$  = activity at a given time       $A_0$  = original activity       $n$  = number of half-lives

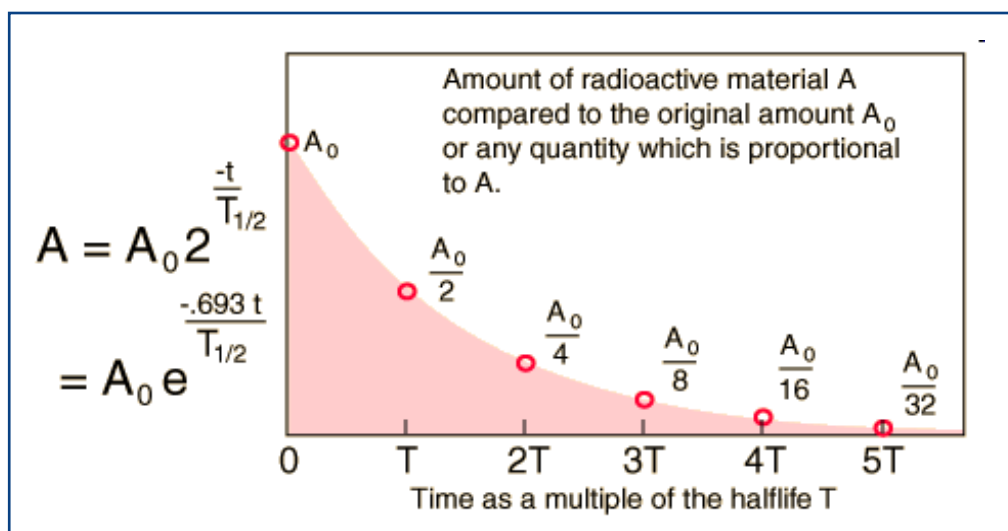


Figure 12: Radioactive half-life (Hyperphysics, 2017)

### Example

If 37 GBq of  $^{32}\text{P}$  was purchased, how much  $^{32}\text{P}$  would be left one year later? The radiological half-life of  $^{32}\text{P}$  is 14.3 days.

The number of half-lives of  $^{32}\text{P}$  in 1 year would be:

365/14.3 which equals 25.5 half-lives

Therefore:

$n = 25.2$ ,       $A_0 = 37 \text{ GBq}$

$A_t = 37 \text{ GBq} / 2^{25.5}$



## 4.10 Properties of radionuclides

The properties of radionuclides can help assess the level of risk associated with the use of a radiation source. For example, in Appendix A: Properties of Commonly Used Radionuclides the *Radio-toxicity Group* assigns a number from 1 to 4 against each isotope. The higher the radio-toxicity group number the more toxic the isotope.

## 4.11 Background radiation

Background radiation refers to radiation that is continuously present in the environment. It is the result of a combination of natural and artificial sources.

### Naturally occurring sources include:

1. Sources from the earth

These may be naturally occurring minerals that contain radiation sources. These will eventually find their way into water and food. Additionally, building materials also contain radiation source.

2. Sources from space

These are cosmic rays.

3. Sources in the atmosphere

A significant contributing factor is radon gas. This is released from the earth's crust and subsequently attaches to airborne dust and particulates.

### Artificially occurring sources include:

1. Sources from the medical industry

These include both diagnostic investigations and therapeutic treatments.

2. Sources from industry

These are mainly in the fields of measurement and scientific research.

3. Sources from nuclear fall out

These are from nuclear weapon testing, incidents and detonations around the world.

The relative annual per capita dose in Australia from various sources of radiation is approximately 3.2 mSv (Figure 13) with the largest significant contributing exposure to background radiation is from diagnostic medicine (53%). This is followed by terrestrial sources at approximately 19%.

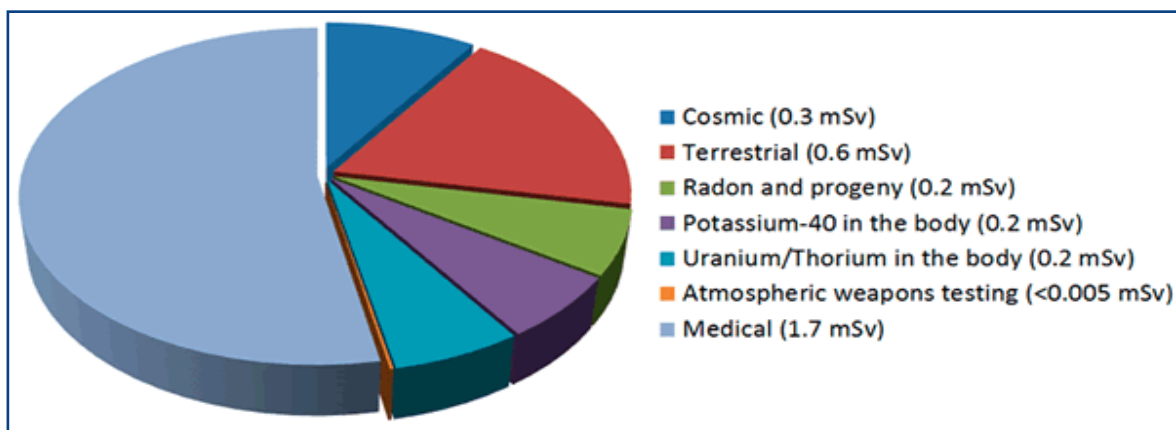


Figure 13: Relative annual per capita dose to the Australian population from various radiation sources (ARPANSA, 2017)

Background ionising radiation levels (from natural radiation sources) in Australia are relatively small in comparison to the other countries (Figure 14). Data from the World Nuclear Association (2017) places Finland with the highest background level at just under 8mSv per annum. Australia and the UK show the lowest annual background ionising radiation level of less than 2 mSv per annum.

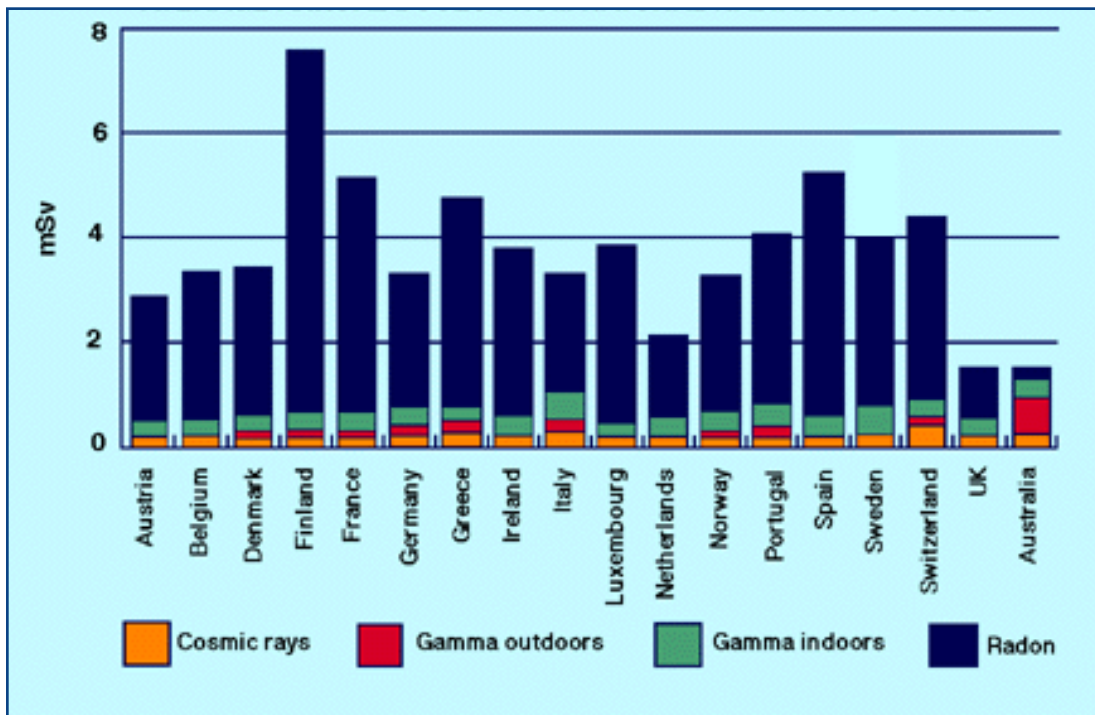


Figure 14: Average annual doses from natural radiation sources (World Nuclear Association (2017))

## 4.12 Background radiation and dose limits

In Section 2.2.4 it was determined that dose limits were regulated by the *Radiation Regulations 2017* (Vic). In Section 3.5 it was also determined that ionising radiation practices at the University would be limited to that of a member of the public (1 mSv per annum) and not the occupational dose limits as prescribed by the *Radiation Regulations 2017* (Vic).

When dose limits are assessed they consider the background radiation. For example, the background radiation in Victoria is approximately 2.5 mSv per annum. This means that University staff and students at the Parkville campus would need to receive above 2.5 mSv per annum before it was considered that they had received a radiation dose from their activities.

## 4.13 Sourcing further information

Description of Information	Where to Obtain
<i>Ptable</i> (Dayah M, 2017) <ul style="list-style-type: none"><li>Reference to the periodic table including a function that describes the physical properties of chemical elements (radiological isotopes).</li></ul>	<a href="https://ptable.com">https://ptable.com</a>
Dictionary of Radiation Terms	<a href="https://www.remm.nlm.gov/dictionary.htm">https://www.remm.nlm.gov/dictionary.htm</a>

## 4.14 References

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## 5 BIOLOGICAL EFFECTS AND POTENTIAL EXPOSURES

### 5.1 Cell and tissue damage

The mechanisms of biological damage of ionising radiation can be described as follows:

Injury to living tissue results from the transfer of energy to atoms and molecules in the cell structure. Ionising radiation causes atoms and molecules to become ionised or excited.

These excitations and ionisations can:

- produce free radicals;
- break chemical bonds;
- produce new chemical bonds and cross-linkage between macromolecules; and
- damage molecules that regulate vital cell processes (e.g. DNA, RNA, proteins).

Damage to the cell (Figure 15) may include:

- cell death;
- free radicals;
- chromosomal aberrations;
- mutations; and
- genomic instability.

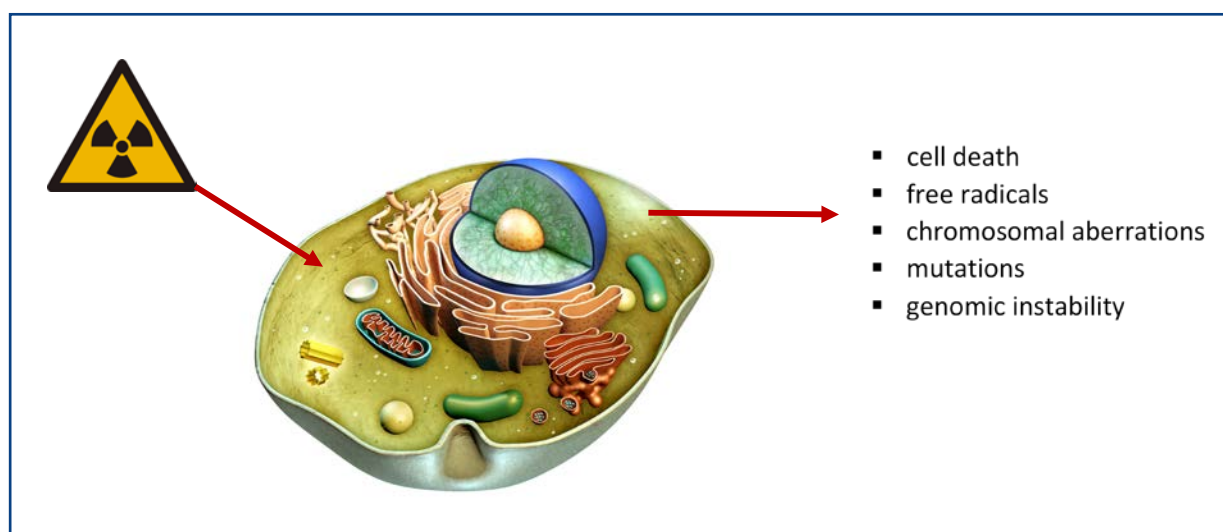


Figure 15: Possible cell<sup>11</sup> damage from exposure to radiological material

The cell can repair certain levels of cell damage. At low doses, such as that received every day from background radiation, cell damage is rapidly repaired. At higher levels, cell death results. At extremely high doses, cells cannot be replaced quickly enough, and tissues and organs can fail resulting in death.

<sup>11</sup> Cell image from Centre for Innate Immunity and Immune Disease (2017).

## 5.2 Physical factors

The physical factors that influence the effects of ionising radiation include:

- the type, the activity and the energy the ionising radiation;
- whether it is an external ionising radiation source or a contamination that could lead to internal exposure; and
- whether the whole body or part of the body is irradiated.

Biological effects from ionising radiation are dose dependent. In general, the radiation sensitivity of a tissue is:

- proportional to the rate of proliferation (multiplication) of its cells; and
- inversely proportional to the degree of cell differentiation (structurally and functionally different).

## 5.3 Biological half-life

Biological half-life is the time required for living tissue, such as an organ in the human body, to eliminate one half of a radioactive substance which has been introduced into it.

As previously determined radiological half-life is the time required for a radionuclide, or radioactive isotope, to decay to one-half its original activity. Furthermore, the radiological half-life of an isotope is a physical constant that is unaffected by the physical or chemical conditions around it. However, when a radioisotope is introduced into biological system it can be stored or excreted by the organism. This changes the ionising radiation internal exposure to the organism.

The rate of excretion from the body will significantly affect the biological half-life. In addition, the biological half-life is not constant and is not as precise as the physical half-life.

In some cases, the rate of radiological excretion (biological half-life) may be more significant than physical decay of the radiological nuclide.

### Example

Consider  $^3\text{H}$ , it has a radiological half-life of 12.3 years. However, it clears from the body quickly (with a biological half-life 12 days) thus significantly reducing the exposure.

## 5.4 Effective half-life

The radiological half-life and the biological half-life for a given radioisotope interact to decrease the radiation exposure from a given radioisotope. The effective half-life is where the original radioactivity in an organism reduces by 50% through the combination of radioactive decay (radiological half-life) and biological excretion (biological half-life). In Table 11 this relationship is shown with numerous radioisotopes.

The effective half-life is determined by the following equation:

$$T_{\text{eff}} = \frac{T_r \times T_b}{T_r + T_b}$$

$T_{\text{eff}}$  = effective half-life

$T_r$  = radiological half-life

$T_b$  = biological half-life

### Example

For  $^{59}\text{Fe}$   $T_r$  = 45 days and  $T_b$  = 600 days

The effective half-life is:  $45 \times 600 / 45 + 600 = 41.86$  days

Isotope	Half-lives in days		
	T <sub>Radiological</sub>	T <sub>Biological</sub>	T <sub>Effective</sub>
<sup>3</sup> H	4.5 x 10 <sup>3</sup>	12	12
<sup>14</sup> C	2.1 x 10 <sup>6</sup>	40	40
<sup>22</sup> Na	850	11	11
<sup>32</sup> P	14.3	1155	14.1
<sup>35</sup> S	87.4	90	44.3
<sup>36</sup> Cl	1.1 x 10 <sup>8</sup>	29	29
<sup>45</sup> Ca	165	1.8 x 10 <sup>4</sup>	164
<sup>59</sup> Fe	45	600	42
<sup>60</sup> Co	1.9 <sup>3</sup> x 10 <sup>3</sup>	10	10
<sup>65</sup> Zn	244	933	193
<sup>86</sup> Rb	18.8	45	13
<sup>90</sup> Sr	1.1 x 10 <sup>4</sup>	1.8 x 10 <sup>4</sup>	6.8 x 10 <sup>3</sup>
<sup>99m</sup> Tc	0.25	1	0.20
<sup>123</sup> I	0.54	138	0.54
<sup>131</sup> I	8	138	7.6
<sup>137</sup> Cs	1.1 x 10 <sup>4</sup>	70	70
<sup>140</sup> Ba	12.8	65	10.7
<sup>198</sup> Au	2.7	280	2.7
<sup>210</sup> Po	138	60	42
<sup>226</sup> Ra	5.8 x 10 <sup>5</sup>	1.6 x 10 <sup>4</sup>	1.5 x 10 <sup>4</sup>
<sup>235</sup> U	2.6 x 10 <sup>11</sup>	15	15
<sup>239</sup> Pu	8.8 x 10 <sup>6</sup>	7.3 x 10 <sup>4</sup>	7.2 x 10 <sup>4</sup>

Table 11: Radiological and biological half-life (Tuszynski and Dixon, 2001)

## 5.5 Deterministic and stochastic effects

The biological effect of ionising radiation, considering the dose, can be divided into two categories:

- deterministic effect; and
- stochastic effect.

### 5.5.1 Deterministic effects

The severity of the effects of ionising radiation on human beings will increase with increasing doses. There exists a certain level, the "threshold", below which the effect will be absent. Above this threshold adverse biological effects called "deterministic effects" will occur.

Characteristics of deterministic effects:

- damage depends on the absorbed dose; and
- threshold exists.

#### NOTE:

**Deterministic effects** have a threshold below which the **effect** does not occur. The threshold may be very low and may vary from person to person. However, once the threshold has been exceeded, the severity of an **effect** increases with dose.

Some examples of deterministic effects include:



- cataracts;
- reddening of the skin;
- burns;
- hair loss;
- blood changes;
- temporary or permanent sterility;
- nausea;
- CNS damage; and
- death.

Table 12 provides thresholds for parts of the body in which deterministic effects have been established.

Threshold for Deterministic Effects (Gy)			
Body location	Effects	Total dose in a single exposure (Gy)	Annual doses in case of fractioned exposure (Gy/year)
testicles	temporary sterility	0.15	0.4
	permanent infertility	3.5 - 6.0	2
ovaries	sterility	2.5 - 6.0	> 0.2
lens of eyes	detectable opacities	0.5 - 2.0	> 0.2
	cataracts	5.0	> 0.15
bone marrow	depression of haematopoiesis	0.5	> 0.4

Table 12: Threshold for deterministic effects (Gy) to parts of the body (ICRP, 2007)

### 5.5.2 Stochastic effects

Unlike deterministic effects the severity of stochastic effects is independent of the absorbed dose. This means that stochastic effects are not dose dependent and are therefore not predictable. Under certain exposure conditions, the effects may or may not occur. There is no threshold and the probability of having the effect is proportional to the dose absorbed.

Characteristics of stochastic effects:

- severity is independent of absorbed dose;
- threshold does not exist; and
- probability of occurrence depends on absorbed dose.

#### NOTE:

Stochastic effects increase with dose. Stochastic effects lack the threshold dose since injury to few cells or even a single cell could theoretically result in an effect.

Some examples of stochastic effects include:

- radiation induced cancers; and
- genetic effects/changes.

As stochastic effects of radiation have no thresholds and can cause cancers or genetic modifications, of which the curing rates are rather low to date, they become a major subject of research in radiation protection.

## Cancer

Cancers that have been associated with radiation exposure include leukaemia, multiple myeloma, breast cancer, lung cancer, and skin cancer.

Radiation-induced cancers may take 10 to 15 years or longer to appear.

Studies of people exposed to high doses of radiation have shown that there is an increased risk of cancer associated with high doses. There may be a risk of cancer at low doses as well.

## 5.6 Routes of exposure

Radiation exposures can be divided into two groups, namely, external and internal. These routes of exposure must be considered together when assessing the total hazard as follows:

- external hazards; and
- internal hazards.

### 5.6.1 External hazards

External hazards arise from sources of ionising material outside the body that can irradiate all or part of the body with sufficient energy to affect the skin and/or underlying tissues.

Alpha radiation is not considered an external ionising radiation hazard, as it cannot penetrate the outer layers of the skin.

Practical control measures will centre on reducing these exposures and are detailed in Section 6.2.

#### External Radiation

Radiation that comes from a radiation source outside the body.

### 5.6.2 Internal hazards

Internal hazards arise when radiation sources enter the body through inhalation, injection, ingestion or absorption through the skin or a wound. An intake of radioactive substance may be rapidly eliminated from the body or some proportion of the intake may become incorporated into organ(s) with a slower rate of elimination.

Internal control measures will differ from external control measures. These are detailed in Section 6.3.

#### Internal Radiation

Radiation that is introduced into the body from a radiation source.

When different elements enter the body, they will accumulate in specific organs and/or tissues (Figure 16). These are referred to as target organs or tissues.

For example, when iodine is ingested it will accumulate in the thyroid. Therefore, when  $^{131}\text{I}$  is ingested the main biological effects/changes due to ionising radiation will occur in the thyroid.

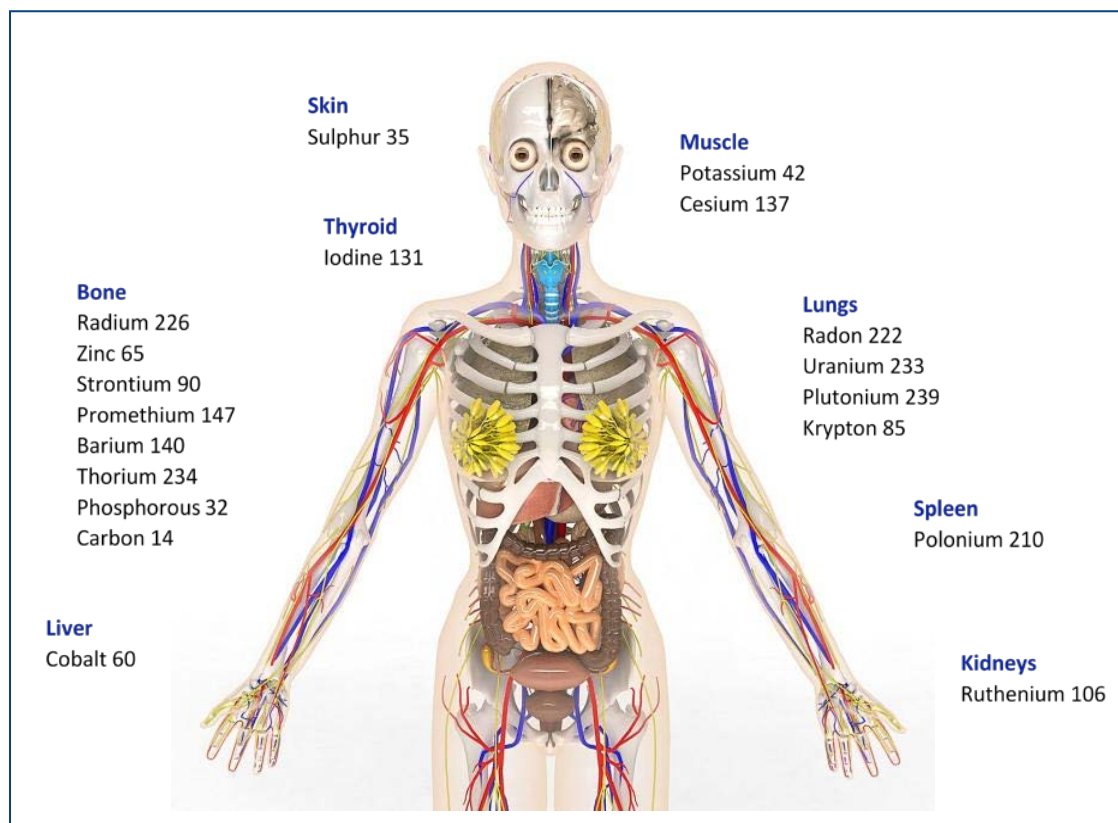


Figure 16: Target organs and tissues from internal exposure to radioactive isotopes

## 5.7 Putting risk into perspective

The following discussion puts into perspective the risks associated with ionising radiation. It highlights that under normal circumstances, where undertaking activities that use ionising radiation, the risk of exposure and subsequent adverse effects are very low.

Firstly, consider the number of "days lost" out of a population due to early death from a given cause, then distribute those days lost over the population. This determines an estimated loss of life expectancy (LLE) due to the given cause. In Table 13 the estimated loss of life expectancies of various health risks are listed, including radiological exposure (occupational dose of 3 mSv/year).

Health Risk	Loss of Life Expectancy (LLE)
Heart disease	4.4 years
Cancer	3.4 years
Stroke	250 days
Smoking 20 cigarettes a day	6.6 years for men/3.9 years for women
HIV	55 days
Overweight	1 year/10 pounds overweight
Alcoholic	12 years
All incidents	366 days
Remaining single	5 years
Occupational dose of 3 mSv/year	15 days

Table 13: Examples of loss of life expectancy (Cohen, 2003)

### CONSIDER:

The LLE from an occupational dose of radiation of 3 mSv/year is 15 days.

This is significantly lower than other health risks such as heart disease and cancer (4.4 and 3.4 years respectively).

Secondly medical procedures present another significant source of radiological exposure. Most of this exposure is from therapeutic and/or diagnostic imaging, such as x-rays and computed tomography scans.

Table 14 shows the dose a person could receive if undergoing an entire procedure that may be diagnostic or interventional (therapeutic).

Examinations and Procedures	Effective Dose (mSv)
Intravenous Pyelogram	3
Upper GI	6
Barium Enema	7
Abdomen Kidney, Ureter, Bladder	0.7
CT Head	2
CT Chest	7
CT Abdomen/Pelvis	10
Whole-Body CT Screening	10
CT Biopsy	1
Calcium Scoring	2
Coronary Angiography	20
Cardiac Diagnostic and Intervention	30
Pacemaker Placement	1
Peripheral Vascular Angioplasties	5
Noncardiac Embolization	55
Vertebroplasty	16

#### CONSIDER:

The average annual effective dose for University staff (0.05 mSv) is 200 times less than the expected effective dose from an abdominal CT Scan (10 mSv).

Table 14: Radiation exposure from medical procedures (Health Physics Society, 2020)

Finally, Table 15 compares the biological outcome from differing doses of external radiation exposure. The table highlights that the average annual exposure of University staff working with ionising radiation is below that of the permitted public exposure.

Dose	Outcome
10 Sv	An acute dose would cause immediate illness and subsequent death within weeks
5 Sv	An acute dose would cause illness and subsequent death (without medical treatment) for 50% of people within 30 days
1 Sv	An acute dose would cause illness such as nausea in 5% of people within a week
100 mSv	Average lifetime risk of death from cancer acute exposure is estimated to be 0.8%
20 mSv	Occupational exposure limit per year
2 mSv	Annual exposure to all individuals from natural sources in Melbourne (background)
1 mSv	Public exposure limit per year
1 mSv	Whole body exposure limit for the University
0.1 mSv	A risk of death from cancer of approximately 1 in 1,000,000
0.05 mSv	Average annual (whole body) dose equivalent at the University

Table 15: Effects of whole body exposure from differing doses of external radiation

## 5.8 Sourcing further information

Description of Information	Where to Obtain
ARPANSA	<a href="http://www.arpansa.gov.au/">http://www.arpansa.gov.au/</a>
The Department of Health (Cth) <ul style="list-style-type: none"><li>• Ionising radiation and human health</li></ul>	<a href="http://www.health.gov.au/internet/publications/publishing.nsf/Content/ohp-radiological-toc~ohp-radiological-05-ionising">http://www.health.gov.au/internet/publications/publishing.nsf/Content/ohp-radiological-toc~ohp-radiological-05-ionising</a>

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Cohen, B L, 2003. 'Risks in perspective', *Journal of American Physicians and Surgeons*, vol 8, no. 2, pp. 50-53.

Health Physics Society, 2020. Radiation exposure from medical exams and procedures, Health Physics Society, viewed 22 February 2021, < [https://hps.org/documents/Medical\\_Exposures\\_Fact\\_Sheet.pdf](https://hps.org/documents/Medical_Exposures_Fact_Sheet.pdf)>

International Commission of Radiological Protection (ICRP), 2007. *Recommendations of the International Commission on Radiological Protection*, ICRP Publication 103, Ann. ICRP 37 (1-332).

Tuszynski J A and Dixon J M, 2001. *Biomedical applications of introductory physics*, John Wiley and Sons Inc., USA.

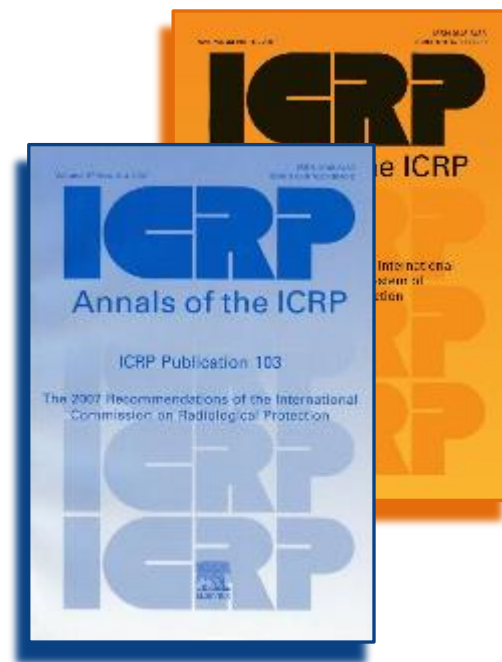
## 6 IONISING RADIATION PROTECTION PRINCIPLES

### 6.1 Three principles of radiological protection

In 1971 the ICRP proposed a system for the dose limitation of ionising radiation based on three principles of radiological protection (ICRP, 1971). Whilst the publication of 1971 has been superseded by Publication 103 (ICRP, 2007) the three principles have remained.

To summarise the three principles of radiological protection are:

- **justification** of radiological exposure  
Any decision that alters the radiation exposure situation should do better than harm (Publication 103 paragraph 203)
- **optimisation** of protection  
Doses<sup>12</sup> should all be kept as low as reasonably achievable, considering economic and societal factors (Publication 103 paragraph 203)
- individual **dose limitation**  
The total dose to any individual ... should not exceed the appropriate limits <sup>13</sup>(Publication 103 paragraph 203)



#### 6.1.1 Justification

The first principle, justification of radiological exposure requires that the benefits derived from the use of a radiation source outweigh the risk of injury from the ionising radiation exposure because of that use.

Before any activity or procedure involving exposure to radioactivity is commenced it is important to ask what are the risks associated with the activity. What are the expected exposures and will these exposures be justifiable? A radiological diagnostic procedure is an example of the justification principle. Here the risks associated with the radiation exposure to the patient are outweighed by the benefits of the required diagnosis.

#### 6.1.2 Optimisation

The second principle, optimisation of protection requires that resources are utilised to their most advantageous to minimise radiation risks.

For example, the dose rate of a hypothetical laboratory process exposes staff to 1.5 mSv per year. To reduce the exposure through engineering controls by 0.5 mSv may cost the School/Business division thousands of dollars. It would be more practical (and optimal) to reduce the duration of the activity. This control may also have associated costs but are likely to be far less than the engineering alternative.

##### ALARA

The principle of optimisation can be expressed by the acronym ALARA:

##### As Low as Reasonably Achievable

ALARA requires that the exposure to justified activities should be kept as low as reasonably achievable, social and economic factors being considered.

<sup>12</sup> Absorbed dose (Section 4.8.4), equivalent dose (Section 4.8.5) and effective dose (Section 4.8.7)

<sup>13</sup> The dose limits are regulated by the *Radiation Regulations 2017* (Vic) (Section 2.2.4)

### 6.1.3 Limitation

The third principle, individual dose limitation requires that all exposures to radiation are kept to their absolute minimum to achieve a desired outcome. The aim is to ensure that no person is exposed to an unacceptable risk under normal circumstances.

The “absolute minimum” will be defined by the specified dose limit. For example, the dose limit for radiation exposure at the University is 1 mSv per year. Therefore, the principle of limitation requires that all activities at the University will not expose staff and students to >1 mSv per year.

## 6.2 Controls determined by routes of exposure

Not only are the physical properties of an ionising source considered when planning controls to limit/minimise exposure but also the route (or possible route) of radiological exposure is considered.

In Section 5.6 radiological exposures routes were divided into:

- external; and
- internal

Therefore, planning controls to limit radiological dose should consider both external and internal exposure.

## 6.3 Controls to prevent external exposure

The three primary means for eliminating or reducing external radiological exposure are:

- time;
- distance; and
- shielding.

### 6.3.1 Time

The dose accumulated by a person working in an area with a dose rate that is directly proportional to the amount of time spent in the area. In other words, the less time a person is exposed to an external ionising radiation source the smaller the dose.

The dose is determined by the following equation:

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



**Note:** In the occupational framework, the calculation assumes that a person will work 50 weeks a year. With an annual dose limit at the University of 1mSv, the weekly dose rate cannot exceed 20 µSv per week over 50 weeks.

#### Example

The annual dose rate for staff at the University is 1 mSv per year (or 20 µSv per week).  
How many hours could a staff member work in a laboratory with a dose rate of 10 µSv/h?

$$20 \mu\text{Sv/week} = 10 \mu\text{Sv/hour} \times \text{time}$$

$$\text{Time} = 2 \text{ hours per week}$$



### 6.3.2 Distance

Gamma, x-ray or neutron point source of radiation emits uniformly in all directions. The dose rate from this point source is inversely proportional to the distance from the source squared (Figure 17). This is known as the inverse square law and is determined by the following equation:

$$\text{Dose rate} = 1/\text{distance}^2$$

This can also be expressed as:

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

**D** = dose rate                      **r** = distance (radius)

Where  $D_1$  is the dose rate at distance  $r_1$  from the source and  $D_2$  is the dose rate at  $r_2$  from the source.

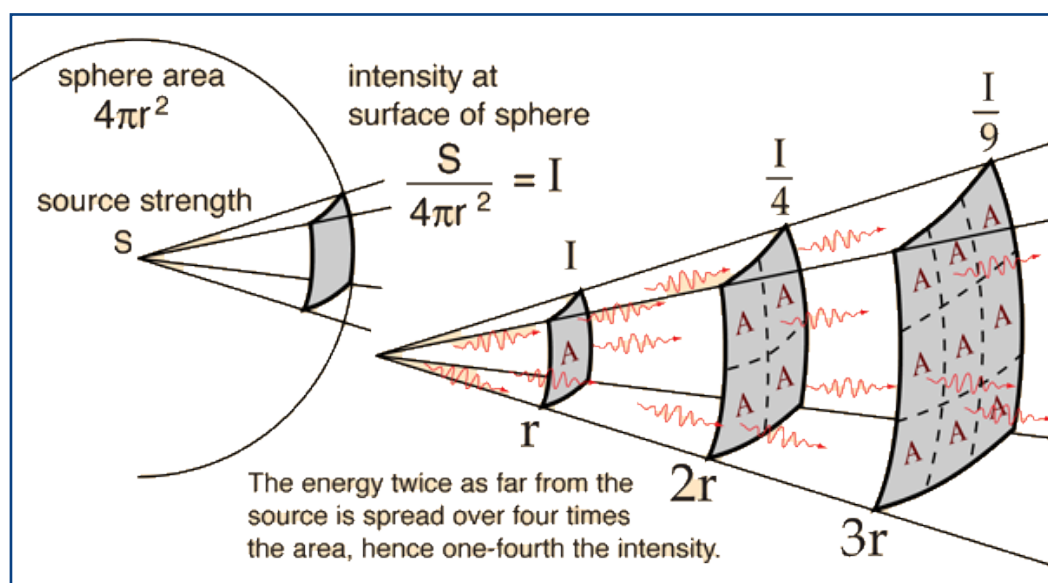


Figure 17: Inverse square law (HyperPhysics, 2017)

The previous equation does not accurately measure the dose rate from a gamma source. The “gamma ray constant” is required for this purpose. The gamma ray constant provides the dose at a predetermined distance (1 metre) for a gamma emitting radionuclide measured in  $\mu\text{Sv/h}$ . Each radionuclide will have a respective gamma ray constant. The gamma ray constants for commonly used radionuclides are detailed in Appendix A.

The dose rate for a gamma sources is determined by the following equation:

$$\text{Dose rate} = \Gamma A / r^2$$

**$\Gamma$**  = gamma ray constant in  $\mu\text{Sv/h}$                       **A** = activity in GBq                      **r** = distance in metres (radius)

### 6.3.3 Shielding

The purpose of shielding is to ensure that the dose received by any person is below the specified dose limits. The proper selection and use of shielding can enable a person to work closer and longer to a source of ionising radiation than an unshielded source.

Shielding is used for radiation sources that emit x-rays, gamma rays, beta particles or neutrons.

#### NOTE:

Distance is not considered a primary means of reducing exposure to alpha and beta particles given that they travel only a short distance through the air.

#### NOTE:

Shielding is not considered a primary means of reducing exposure to alpha particles given that alpha particles are “stopped” on contact with any surface, including the skin.

## Alpha Radiation

As previously determined alpha particles are easily absorbed and are not considered an external hazard to the body. The skin will act as a barrier stopping the alpha particles from being absorbed into the body.

Alpha particles will quickly ionise in air and therefore shielding is normally not required. A thin sheet of paper is sufficient to stop alpha particles and so they never present a shielding problem.



A thin sheet of paper will shield alpha particles.

## Beta Radiation

Beta radiation is more penetrating than alpha radiation. For example, the energy range 1 – 2 MeV, normally encountered with beta radiation, requires shielding of up to 10 mm of perspex for complete absorption.

### *Bremsstrahlung*

A problem encountered when shielding high activity/high energy beta radiation is the emission of secondary x-rays. These result from a rapid slowing down of beta particles. This process is known as bremsstrahlung. Therefore, beta shields should be constructed of material with low mass number, such as aluminium or perspex, to reduce the number of x-rays being emitted.



Perspex can be used to shield beta particles.

## Neutron Radiation

Neutrons do not have a charge and therefore they do not interact readily with surrounding matter. This means they can travel/penetrate appreciable distances. Hydrogen both scatters and slows neutrons. This means that neutron shielding requires the use of materials which contain significant amounts of hydrogen, such as paraffin wax, concrete or water.



Paraffin (such as borated paraffin) can be used to shield neutron particles.

## X-Ray and Gamma Ray

For shielding x-ray and gamma ray radiation a material with high atomic number is required, such as lead. Lower atomic number materials, such as steel or concrete, can be used but will need correspondingly greater thickness.

### Z number

Atomic number is defined as the Z number. Therefore, shielding requirements for x-rays and gamma rays are often referred to as materials with a high Z number.



Lead can be used to shield to shield x-rays and gamma rays.

## Half-Value Layer

The half-value layer (HVL) of a shield quantifies the thickness of the shield. When the shield is placed in front of a radiation source it will reduce the intensity of that source by half.

Half-value layer is determined by the following equation:

$$I = I_0/2^n$$

I = shielded dose rate

$I_0$  = unshielded dose rate

n = number of half-value layers

## Tenth-Value Layer

Like the HVL, the tenth-value layer (TVL) of a shield also quantifies the thickness the shield. In this case when the shield is placed in front of a radiation source it will reduce the intensity of that source by a factor of ten.

Tenth-value layer is determined by the following equation:

$$I = I_0/10^n$$

I = shielded dose rate

$I_0$  = unshielded dose rate

n = number of tenth-value layers

Typical shields for gamma rays and x-rays are measured in half-value and tenth-value layer thickness.

Table 16 lists examples of radiation sources emitting gamma rays and their corresponding shielding requirements.

Isotope	Mean Energy	Half-life	HVL Pb (mm)	TVL Pb (mm)
<sup>60</sup> Co	1.25 MeV	5.26 years	11	33.9
<sup>226</sup> Ra	1.03 MeV	1,626 years	16	28.9
<sup>137</sup> Cs	662 keV	30 years	6.5	18.5
<sup>192</sup> Ir	360 keV	74.2 days	3.1	7.1
<sup>222</sup> Rn	1.03 keV	3.83 days	1.6	2.9
<sup>198</sup> Au	412 keV	2.7 days	3.3	8.9
<sup>125</sup> I	28 keV	59 days	0.025	0.38
<sup>103</sup> Pd	22 keV	17 days	0.013	0.21
<sup>169</sup> Yb	93 keV	32 days	1.6	3.1

### APPLICATION:

When applying the half-value layer or tenth-value layer, ensure that the type of material used is stated.

Table 16: HVL and TVL shielding requirements gamma rays (Jones, 2003)

## Summary of Shielding

Table 17 provides a summary of radiation properties and their relationship to shielding requirements.

Type of Radiation	Symbol	Electrical Charge	Penetration	Ionising Strength	Shield Material
alpha (helium nuclei)	$\alpha$	+ + charge	short	strong	paper, skin
beta (electrons)	$\beta$	- charge	moderate	moderate	aluminium, perspex
neutron (neutrons)	n	no charge	short to high	weak to strong	hydrogen rich eg. paraffin, water
Gamma	$\gamma$	no charge	high	weak	lead, concrete
X-ray	X	no charge	high	weak	lead, concrete

Table 17: Summary of radiation properties and shielding requirements

## 6.4 Controls to prevent internal exposure

The principles of internal protection/contamination control are:

- minimise;
- contain; and
- clean; and

Staff and student training which is essential to the prevention of radiological exposure is discussed in Section 11.1 and includes:

- local induction for new staff and students; and
- ionising radiation safety training.

### Radioactive contamination

is a radiation source in any unintended location and predominantly where its presence may be harmful or result in a radiation risk.

### 6.4.1 Minimise

Using the smallest activity of the radiation source that is suitable for the task reduces the risk of internal contamination.

Using fume hoods and avoiding dust, aerosol, or volatile gas production can reduce the potential for inhalation of radioactive substances.



### 6.4.2 Contain

The following containment controls will assist in the prevention of internal exposure.

- restrict access to the where the sources are used – keep a list of authorised users and ensure that unauthorised staff, students and others cannot access the radiation sources
- limit the area where sources are used – provide a designated space for radiation activities in the laboratory
  - sign area appropriately with a radiation sign
- provide adequate ventilation – fume hoods
- use personal protective equipment – gloves, laboratory coats, glasses
- label containers with radioactive symbol



### 6.4.3 Clean

Strict hygiene practices in the laboratory reduces the likelihood of internal contamination. This includes:

- employing a high standard of housekeeping techniques
  - cleaning benches regularly
  - washing hands
  - do not store unused isotopes on benches/areas where they can be inadvertently knocked
- determine laboratory rules that include, no smoking, eating or drinking
- monitor area and staff on a regular basis and the end of the activity to ensure there is no contamination to clothing or skin



## 6.5 Effective control

### 6.5.1 Summary of effective control

#### Effective control

The safe use and effective control of radiation requires:

- **Knowledge**  
A thorough understanding of the radiological material been used.
- **Skills and experience**  
Previous experience utilising safe working controls with radiological materials.
- **Work practices.**  
Continuing use of safe work practices.

## 6.5.2 Case study of effective control

### Background

In February 2009 after months of planning a 7 TBq of  $^{60}\text{Co}$  was removed from the University. The University contracted Australian Nuclear Science and Technology Organisation (ANSTO) to undertake this work.

### Procedure

The  $^{60}\text{Co}$  source was contained in a large shielded vessel.

To remove the source from the University and transport it to another location several steps were involved.

These included:

- opening the containment vessel;
- removing the  $^{60}\text{Co}$  from the containment vessel; and
- placing the  $^{60}\text{Co}$  in a shielded transport vessel.

The entire activity, including the planning phase took 7 hours to complete.



The containment vessel



Lifting the containment vessel.



Using fibre optics to view the  $^{60}\text{Co}$  from inside the vessel

The containment vessel was a Class B container. Due to its shielding, it weighed 2755kg.

### Radiation dose

The technicians from ANSTO received a radiation dose of 14  $\mu\text{Sv}$  from this activity. In comparison whilst flying from Sydney to Melbourne they had received 7  $\mu\text{Sv}$ .

### Summary

This case study highlights that with appropriate controls in place irrespective of the radioactivity of the source, it is achievable to keep dose exposures very low.

In summary, effective control of radiation required:

- knowledge – the technicians understood the radiological properties of  $^{60}\text{Co}$  and the subsequent risks
- skill and experience – the technicians had extensive skills and experience working both with  $^{60}\text{Co}$  and other radiological materials with a high activity
- work practices – the technicians applied adhered to standard operating procedures developed specifically for the activity.

## 6.6 Sourcing further information

Description of Information	Where to Obtain
ARPANSA	<a href="http://www.arpansa.gov.au/">http://www.arpansa.gov.au/</a>
<i>Guide for radiation protection in existing exposure standards</i>	<a href="https://www.arpansa.gov.au/sites/g/files/net3086/f/rpsg-2-existing-exposure.pdf">https://www.arpansa.gov.au/sites/g/files/net3086/f/rpsg-2-existing-exposure.pdf</a>
<i>AS 2243.4 Safety in laboratories. Part 4. Ionizing radiations</i>  Australian Standards (accessed via SAI Global)  A University user name and password is required.	<ol style="list-style-type: none"><li>1. Log-on to the University library</li><li>2. You will need to search for SAI Global</li></ol>

## 6.7 References

International Commission of Radiological Protection (ICRP), 1971. Recommendations of the International Commission of Radiological Protection, ICRP Publication 26, Ann. ICRP 1 (3).

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Victorian Government, 2017. *Radiation Regulations 2017*, Author, viewed 22 February 2021, <<https://www.legislation.vic.gov.au/in-force/statutory-rules/radiation-regulations-2017/001>>.



## 7 IDENTIFICATION AND STORAGE

### 7.1 Identification requirements

Many radiation sources also have associated chemical properties. Therefore, when naming a container both the chemical(s) and the radiation source(s) must be acknowledged.

#### 7.1.1 Ionising radiation identification requirements

The purpose of identification (such as a label on a container) is to ensure that the radiation source is known. This includes providing basic information about the contents of the container such as:

- the product name;
- the chemical(s);
- the hazards;
- the radioactivity; and
- the precautions for safe use.

The container and the storage location should be clearly marked with a radiation tri-foil symbol (Figure 18). The radiation tri-foil is an internationally recognised symbol for ionising radiation. The tri-foil is black on a yellow background.



Figure 18: Ionising radiation tri-foil symbol



Figure 19: Supplementary ionising radiation symbol

#### Supplementary Ionising Radiation Warning Symbol

In 2007 the International Standardization Organization (ISO) and IAEA published a supplementary ionising radiation warning symbol (Figure 19).

The supplementary symbol is intended to accompany the existing tri-foil, not replace it.

Its intended use includes the following conditions:

- placed on dangerous radiation sources capable of causing death or serious injury;
- placed as a warning not to dismantle or get close to a dangerous radiation source; and
- placed so that it will not be visible under normal use but only where someone attempts to disassemble the radiation source.

The symbol is published in ISO 21482 (IAEA, 2007).

## 7.1.2 Chemical identification requirements

There may be additional identification requirements associated with the chemical contents of the radiological material. The *Occupational Health and Safety Regulations 2017* (Vic) mandate specific requirements for hazardous substances.

The University *Chemical management guidelines* provide instruction on these requirements.

Radioactive chemicals must be identified by a label that is written in English and it should include the:

- radiation tri-foil symbol
- product identifier<sup>14</sup>
- radioactivity

Where a label is required, but it is not practical to label the container with the product name (for example, because the container is too small) some other means to identify the contents of the container should be used (for example, abbreviations/symbols on a label that are displayed on a chart in the area where the chemical is used).

It is important that staff and students likely to be exposed to the substance are informed about the type of the identification method used.

## 7.2 Storage requirements

Storage requirements for radiation sources must consider both the chemical properties and the radioactive properties.

### 7.2.1 Ionising radiation storage requirements

Radiation sources are identified as a Class 7 dangerous good. With regards to *The Dangerous Goods (Storage and Handling) Regulations 2012* Class 7 dangerous goods have specific, storage, transport and placarding requirements. There may be additional placarding requirements for radiation sources and these are discussed in Section 11.5.1.

Cupboards, lockers and refrigerators used for storing radiation sources should be signed to indicate the storage of ionising radiation with the ionising radiation tri-foil symbol (Figure 18). For further guidance also refer to *Health & Safety: Signage requirements*.

Additional signs may also be required, such as “do not use to store food”.

Storage arrangements should include an assessment of the level of risk associated with the use of the radiation source.

Storage arrangements for radiation sources should include restricted access. This will ensure that only trained authorised staff and students can access the radiation source(s). Examples of restricted access include:

- locked cupboards or refrigerators within a laboratory;
- locked laboratories; and
- proximity cards and readers to laboratories and/or or larger areas.

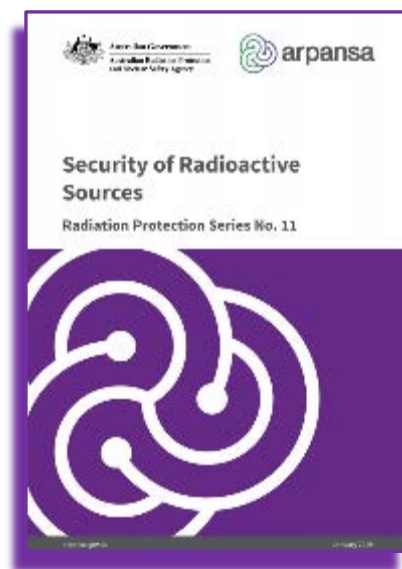
Restricted access may be a combination of the above examples (Table 18).

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<sup>14</sup> Product identifier means the name or number used to identify a product – *Occupational Health and Safety Regulations 2017* (Vic)

Radiation Source	Examples of Storage/Security Arrangements
Low level open sources	Locked refrigerator/cupboard (whichever is applicable) Restricted access to area
X-ray unit	X-ray is locked out when not in use – with a key Restricted access to area
Mobile x-ray unit	Locked store room or cupboard Restricted access to storeroom or cupboard

Table 18: Examples of storage arrangements for radiation sources



There may be additional security requirements for the storage of some radiation sources. These requirements will be stated in the University *management licence*. Where stated the *Code of practice for the security of radioactive sources* (ARPANSA, 2019) must be followed.

University local areas are not normally affected by this code.

## 7.2.2 Chemical storage requirements

Because of their physical properties many chemicals, including radionuclides, have specific but differing storage requirements. The hazards or risks associated with chemical storage can include one or a combination of the following:

- chemicals that become unstable over time that may result in fire or explosion;
- chemicals that are temperature sensitive;
- chemicals that are shock sensitive;
- chemicals with a physical property that are incompatible with chemicals with another physical property;
- chemical packaging may become damaged and leak;
- chemicals may be decanted into inappropriate or unlabelled containers;
- the storage arrangements introduce additional hazards associated with the chemical; and
- there may be licensing conditions or constraints affecting storage requirements.

Storage arrangements should be identified during the chemical risk assessment and appropriate provisions provided. Storage requirements are also normally specified in a safety data sheet (SDS<sup>15</sup>).

Further requirements and guidance on chemical management are outlined in the:

- *Health & Safety: Chemical requirements*; and
- *Chemical management guidelines*.

<sup>15</sup> The *Chemical Management Guidelines* contain additional information on SDS requirements.

## 7.3 Sourcing further information

Description of Information	Where to Obtain
Chemical management guidelines	<a href="https://safety.unimelb.edu.au/_data/assets/pdf_file/0010/1705906/chemical-management-guidelines.pdf">https://safety.unimelb.edu.au/_data/assets/pdf_file/0010/1705906/chemical-management-guidelines.pdf</a>
University Chemical Management web page contains information on:	<a href="http://safety.unimelb.edu.au/safety-topics/chemical-management">http://safety.unimelb.edu.au/safety-topics/chemical-management</a>
University requirement <ul style="list-style-type: none"><li><i>Health &amp; Safety: Chemical requirements</i></li></ul>	<a href="https://safety.unimelb.edu.au/_data/assets/word_doc/0007/1805992/health-and-safety-chemical-requirements.docx">https://safety.unimelb.edu.au/_data/assets/word_doc/0007/1805992/health-and-safety-chemical-requirements.docx</a>
University requirement <ul style="list-style-type: none"><li><i>Health &amp; Safety: Signage Requirements</i></li></ul>	<a href="https://safety.unimelb.edu.au/_data/assets/word_doc/0005/1806926/Health-and-safety-signage-requirements.docx">https://safety.unimelb.edu.au/_data/assets/word_doc/0005/1806926/Health-and-safety-signage-requirements.docx</a>
<i>ISO 21482:2007: Ionizing-radiation warning - Supplementary symbol</i> Australian Standards (accessed via SAI Global) A University user name and password is required.	<ol style="list-style-type: none"><li>1. Log-on to the University library.</li><li>2. You will need to search for SAI Global</li></ol>

## 7.4 References

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 2019. *Code of practice for the security of radioactive sources 2019*, Radiation Protection Series Publication No. 11, Australian Government, viewed 18 February 2019, <<https://www.arpansa.gov.au/regulation-and-licensing/regulatory-publications/radiation-protection-series/codes-and-standards/rps11>>.

International Atomic Energy Agency (IAEA), 2007. *ISO 21482:2007: Ionizing-radiation warning - Supplementary symbol*, International Atomic Energy Agency,

Victorian Government, 2017. *Occupational Health and Safety Regulations 2017*, Author, viewed 22 February 2021, <<https://www.legislation.vic.gov.au/as-made/statutory-rules/occupational-health-and-safety-regulations-2017>>.

Victorian Government, 2021. *The Dangerous Goods (Storage and Handling) Regulations 2012*, Author, viewed 22 February 2021, <<https://www.legislation.vic.gov.au/in-force/statutory-rules/dangerous-goods-storage-and-handling-regulations-2012/007>>.

## 8 MONITORING EQUIPMENT

### 8.1 Radiation monitors

The *Health & Safety: Ionising radiation management plan* requires that where applicable, individuals working with radiation sources wear personal monitoring devices to record the level of radiation they are exposed to while performing their work.

Optically stimulated luminescence (OSL) monitors (Figure 20) are normally used for this purpose. These have replaced the thermoluminescent dosimetry (TLD) monitors for most exposures. TLD monitors are still required for activities where there may be exposure to betas and neutrons.

#### 8.1.1 Optically stimulated luminescence monitor

Where applicable an OSL is provided to staff and students working with gamma radiation and x-rays. The OSL monitor measures potential occupational doses from the gamma radiation and x-ray activities. The OSL monitors cannot detect alpha particles or beta particles.

Each person requiring an OSL monitor is issued with their own personal monitor. These monitors are not interchangeable and cannot be shared with others.

The OSL monitors are compared with the annual allowable dose limits to provide an individual picture of radiation exposure over time.

An OSL monitor can also provide a method of monitoring work practices. For example, if several people undertaking the same activity in the same area show an elevated dose this may indicate a problem with the controls.

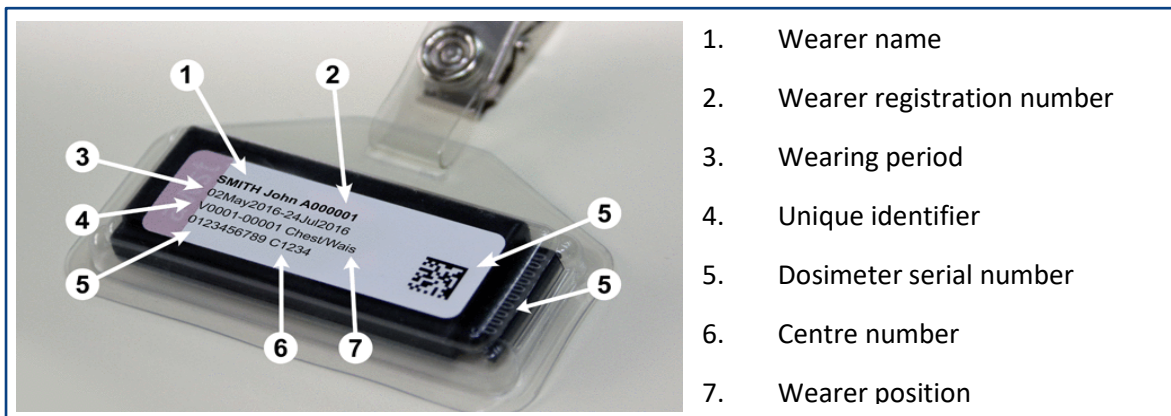


Figure 20: Optically stimulated luminescence monitor

#### OSL monitor requirements

The routine procedure for OSL monitors includes:

- tested quarterly or as appropriate;
- results made available to individuals;
- results stored on file; and
- results made available to the DRSO and the manager/supervisor.

#### NOTE:

An OSL monitor is used only by the person that it is issued to and cannot be shared. If an OSL monitor is lost or damaged it should be reported to the supervisor as soon as possible.

The disadvantage of an OSL monitor is the delay in receiving the results. As the OSL monitor is normally tested on a quarterly basis it means that the dose is unknown for up to three months. Therefore, it is essential to ensure good working practices are in place always.

### 8.1.2 Real time dose monitors

Real time dose monitors are electronic data loggers that provide real time personal dosimetry results.

A real-time monitor can be used for the same purpose as a OSL monitor with additional benefits that include:

- the results are in real time with no delay;
- the results can be downloaded onto a computer and stored on a data base;
- the monitors can be reset and therefore used by several people; and the monitors have pre-set alarm levels.



Figure 21: Examples of real time dose monitors

The University RSA holds a limited number of real time neutron/gamma monitors and beta/gamma monitors (Figure 21) that can be issued to staff for specific needs. The monitor on left in Figure 21 measures neutron/gamma radiation and the monitor on the right measures beta/gamma radiation.

## 8.2 Meters

Radiation meters fall into two main groups (Figure 22):

- survey meters; and
- contamination meters.



Figure 22: Examples of survey and contamination meters

### 8.2.1 Survey meters

Survey meters, also perform as dose rate meters, measure external radiation in units of equivalent dose rate. This means that the measurements are in micro sievert ( $\mu\text{Sv}$ ) per unit of time – hours. They provide a measurement of the rate of radiation received by a person over time.

The purpose of a survey meter is to estimate and control biological (human) ionising radiation exposure.

### 8.2.2 Contamination meters

Contamination meters measure external radiation in units of counts per second (cps) or  $\text{Bq}/\text{cm}^2$ . They provide a measurement of possible contamination in the area being surveyed.

The purpose of a contamination meter is to detect and limit the spread of possible ionising radiation contamination.

**Survey meters and contamination meters** are not interchangeable

A survey meter will give an indication of the radiation dose that a worker is being exposed to. However, a contamination meter will only determine the presence of an isotope but not its dose rate.

### 8.2.3 Considerations

It is important to understand the functions and the limitations of the meter being used. Factors to consider include:

- the type of radiation measured (beta, alpha, gamma etc.);
- the energy levels of the radiation being measured;
- the type and intended use (eg. you cannot use a contamination meter to measure biological risk); and
- the level of efficiency when measuring radiation.

Meters are not 100% accurate at measuring ionising radiation. For example, Table 19 outlines the efficiency levels of a given meter to measure beta emitting isotopes. The accuracy of the result will be influenced by the isotope being measured. Therefore, the operator must know the type of isotope and then based on the percentage efficiency calculate the actual exposure.

Isotope	E <sub>max</sub> 2π (keV)	2π Effic %	Sensitivity cps/Bq/cm <sup>2</sup>	MDL Bq/cm <sup>2</sup>
<sup>14</sup> C	156	3	0.25	9.0
<sup>35</sup> S	167	8	0.65	3.7
<sup>147</sup> Pm	224	15	1.25	2.0
<sup>99</sup> Tc	290	20	1.75	1.5
<sup>90</sup> Sr + <sup>90</sup> Y	580 + 2280	50	8.50	0.3
<sup>36</sup> Cl	714	45	3.50	0.7
<sup>210</sup> Pb	1160	50	4.00	0.6
<sup>32</sup> P	1710	70	5.50	0.5

Table 19: Performance (surface sensitivity – in contact) beta emitting isotopes

### 8.2.4 Purchasing meters

When purchasing a meter, various operational considerations should be considered (Table 20). Operational considerations refer to not only the intended use of the meter but also the meter's functionality.

Operational consideration	Description
Display	Large, clearly understandable, with overflow, low battery, and detector failure
Audio	Audible warning
Units	Counts per second (cps) and/or μSv/h
Controls	Easy to operate with positive feedback
Power Source	Runs on standard (alkaline) battery, with automatic battery check
Detector	A big Geiger Mueller tube (the bigger the better)
Window	Thin front window with a protector cover
Count Rate Range	Large variation in count rate
Sensitivity	High sensitivity with a broad range of energy
Temperature Range	Wide range of operation: -10°C to +50°C and humidity 40% to 95% relative humidity
Case	High impact
Dimensions and weight	Convenient size and low weight

Table 20: Operational considerations when purchasing a radiation meter



## 8.2.5 Operational and calibration requirements

The general operational and calibration requirements for most survey meters are similar with only minor differences (Table 21).

Irrespective of the type of meter, operational and calibration requirements should be in accordance with the manufacturer's/supplier's instruction.

Requirements	Survey Meter	Contamination Meter
General inspection	A general visual inspection should be undertaken for the meter prior to each use. The purpose is to ensure that the meter appears in good working condition. For example, are there any cracks in the meter or does the casing appear damaged?	A general visual inspection should be undertaken for the meter prior to each use. The purpose is to ensure that the meter appears in good working condition. For example, are there any cracks in the meter or does the casing appear damaged? Contamination meters are routinely used in laboratories and will be switched on at the beginning of an activity and remain on for the entire time. The meter can be visually inspected at the beginning of use. Providing conditions do not change there is no need to undertake ongoing visual inspections throughout the activity.
Calibration	Unless otherwise stated by the supplier/manufacturer a survey meter should be calibrated annually. There should be a calibration sticker on the meter that indicates when it was last calibrated and/or the date of next calibration. The owner of the meter should maintain calibration certification documents.	Unless otherwise stated by the supplier/manufacturer a contamination meter does not require annual calibration.  Rationale: A contamination meter only detects the presence of radiation. It does not measure dose rate.
Operational Check	A survey meter should be regularly assessed (weekly) to ensure that it continues to monitor consistently over time.	A contamination meter should be regularly assessed (weekly) to ensure that it continues to monitor consistently over time. The local area should maintain assessment documents.
Battery	Check the battery when first turning on the meter. The meter will have a "battery check" indicator. This may be a needle or as digital display. If it is a needle, check that it moves freely and doesn't stick. If the battery is low, replace it.	Check the battery when first turning on the meter. The meter will have a "battery check" indicator. This may be a needle or as digital display. If it is a needle, check that it moves freely and doesn't stick. If the battery is low, replace it.
Response	Before using the meter check that it is going to respond to radiation. A method for this is to test the meter on a known source in a fixed position.	Before using the meter check that it is going to respond to radiation. A method for this is to test the meter on a known source in a fixed position.

Table 21: Operational and calibration requirements of survey and contamination meters

## 8.2.6 Assessment of a contamination meter

Although a contamination meter does not require the same degree of calibration as a survey meter it should still be assessed regularly to ensure that it continues to monitor ionising radiation consistently over time.

In local areas where radioactive activities occur on a regular basis the contamination meter should be assessed weekly. To assess that a contamination meter continues to monitor consistently over time the following steps should be completed:

1. Place a radiation source with a known activity at a predetermined distance from the contamination meter. Measure the activity of the source.
2. At regular scheduled intervals (eg weekly) repeat the above measurements. Ensure that the radiation source has the same activity and is placed at the same distance from the contamination meter (Figure 23).
3. Compare the measurement results over a defined period. The results should be constant and appear as a flat line on a graph. A steady fall or rise in the results could indicate that the meter is not functioning properly. For example, in Figure 24 the green solid line would represent the expected outcome for a meter that is functioning normally. Whereas the red dotted lines could indicate that the meter is not functioning properly.

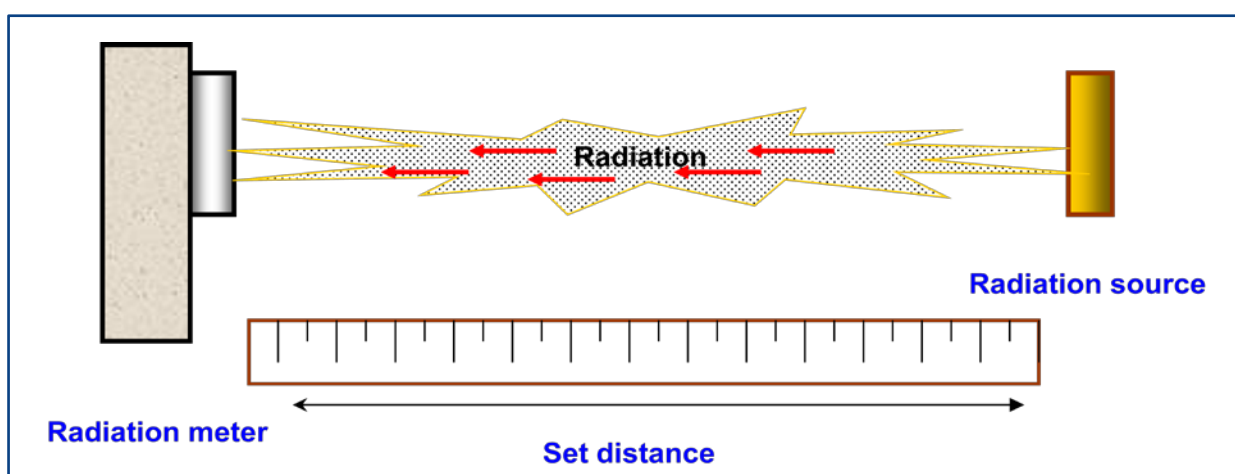


Figure 23: Placement of a radiation source with a known activity at a predetermined distance

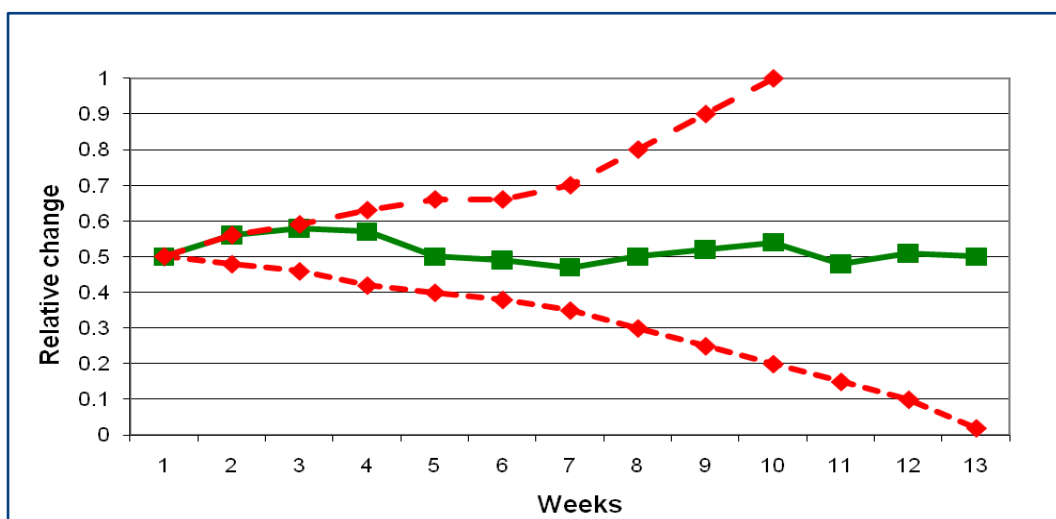


Figure 24: Contamination meter chart showing meter results over time

## 8.3 Radiation survey

In Section 5.6 it was determined that ionising radiation exposure could be external or internal. External exposure would most likely occur from radioactive particulates or electromagnetic radiation in the air (environment around us).

Whereas internal contamination requires taking the radioactive particulates into the body through inhalation, ingestion, absorption or injection.

Radiation surveys are undertaken as additional controls to reduce the likelihood of both external and internal ionising radiation exposure.

Ionising radiation surveys are referred to as “area monitoring” in *AS 2243.4 Safety in laboratories. Part 4. Ionizing radiations*.

In summary, radiation surveys are undertaken to ensure that:

- radiation exposure levels are as low as reasonably achievable; and
- radioactive contamination and/or source leakage does not go undetected.

Radiation surveys that monitor the environment for potential external and/or internal exposures are categorised into three groups. These are:

- external radiation survey;
- surface contamination survey; and
- airborne contamination survey.

Radiation surveys can be undertaken alone or in conjunction with other surveys.

### 8.3.1 External radiation survey

An external radiation survey (also called an area survey) is undertaken to detect external exposure levels from either a removable or fixed source. For example, laboratories that use emitting apparatus, such as x-ray machines require external radiation surveys.

External radiation surveys detect elevated dose rates or increased dose rates from one survey to the next. Where elevated levels are detected action should be taken to reduce exposure.

An area survey can be undertaken in conjunction with other radiation surveys.

### 8.3.2 Surface contamination survey

A surface contamination survey (also called a wipe test or smear test) is undertaken to detect radioactive contamination on surfaces. Contamination may occur where open sources are being used or where the casing/housing of a sealed source becomes compromised.

The survey is undertaken by wiping a surface with an absorbent material such as filter paper. Isopropanol can be used to moisten the filter paper.

After wiping the surface the filter paper is monitored with an appropriate contamination meter in an area of known low radiation background. If the surface was contaminated, particulates would be present on the filter paper and therefore be detected by the meter.

*AS 2243.4 Safety in laboratories. Part 4. Ionizing radiations* states contamination surveys are required where unsealed sources are used and sealed sources such as “high activity neutron sources”.

### 8.3.3 Airborne contamination survey

Airborne contamination surveys are undertaken in areas where activities may produce airborne radioactive contamination or to confirm that a laboratory is free of contamination prior to using the space for other purposes.

Commonly air is drawn across a filter and through a chamber. Both a measurement of the air in the chamber and on the filter, can be taken. Drawing in air from the breathing zone is the most effective method of sampling.

### 8.3.4 Radiation survey requirements

The type and frequency of radiation surveys depends on the task and the radiation source been monitored (Table 22).

Task	Type of Radiation Survey	Frequency	Rationale
Emitting apparatus – x-ray	External	During and immediately after installation	The survey establishes the expected pattern of radiation from the x-ray emitting apparatus. This can then be used as a baseline for subsequent surveys.
		Quarterly	The survey ensures ongoing expected patterns of radiation. Changes in patterns of radiation or elevated levels can indicate damage or compromise to the equipment.
Open source	Surface Contamination	Completion of activity	The survey ensures that on completion of an activity a radiation source is not carried into other areas beyond the designated radiation area.
Radiation store	External survey and Surface Contamination	Annually	The surveys ensure: <ul style="list-style-type: none"><li>• the continued low level of expected radiation; and</li><li>• radioactive contaminants remain intact and are not carried outside the store.</li></ul>

Table 22: Common radiation survey requirements for the University

#### **Mandatory requirements for *use licence* holders**

Where the licence authorises the use of unsealed radioactive material, conduct a radiation survey before and after the use of unsealed radioactive material to confirm the absence of contamination. The survey must be conducted using monitoring equipment that is both appropriate for the radiation being monitored and calibrated at regular intervals not exceeding one year.

Department of Health (2012)

## 8.4 Documentation

Local areas should have arrangements to ensure that results are documented and retained for:

- calibration results and certificates of survey monitors;
- assessment results of contamination monitors; and
- survey results of local areas.

## 8.5 Sourcing further information

Description of Information	Where to Obtain
Health & Safety Services radiation advice email address	<a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a>
DRSO contacts <ul style="list-style-type: none"><li>• Access Business Partner Contacts</li><li>• Navigate to relevant Academic Division</li></ul>	<a href="https://safety.unimelb.edu.au/people/community/local-contacts">https://safety.unimelb.edu.au/people/community/local-contacts</a>
Monitoring Health & Safety web page. Provides information and guidelines for the calibration of health and safety equipment.	<a href="http://safety.unimelb.edu.au/topics/calibration/">http://safety.unimelb.edu.au/topics/calibration/</a>

## 8.6 References

Department of Health, 2017. *Mandatory radiation safety requirements for use licence holders (Use Licence Condition)*, viewed 22 February 2021, <<https://www2.health.vic.gov.au/about/publications/policiesandguidelines/mandatory-radiation-safety-requirements-use-licence-holders-obligations>.

Standards Association of Australia, 2018. *Safety in laboratories. Part 4. Ionizing radiations*, (AS 2243.4 2018), Standards Australia, North Sydney.

## 9 INCIDENTS AND EMERGENCIES

### 9.1 Mandatory reporting of radiation incidents

All holders of a *management licence*, as a condition of the licence, must report “radiation incidents” to the DH. The *Mandatory reporting of radiation incidents* (Department of Health, 2017) prescribe these incidents based on the use of the radiation source and the type of incident.



Examples of radiation incidents include:

- incidents involving non-medical exposures;
- unplanned or abnormal exposures;
- loss of control of a source;
- damaged or malfunctioning source;
- surface, substance or material contamination;
- incidents involving medical exposures (such as burns from x-ray exposure);
- unplanned medical exposures of patients; and
- lost or stolen radiation sources.

Local area emergency and incident procedures must take in to account the requirements for reporting radiological incidents. Therefore, the DRSO should be contacted following any radiation incident to determine if there are mandatory reporting requirements.

The DRSO shall contact the University RSA for clarification and/or assistance following a radiological incident. The University shall notify the DH in the prescribed manner where a radiological incident must be reported.

#### University mandatory reporting requirements

Mandatory reporting requirements are set down as a condition of the University *management licence*.

The *management licence* holder must report any radiation safety incident which occurs in the conduct of the radiation practice in a manner and time consistent with the document titled [Mandatory Reporting of Radiation Incidents](#).

### 9.2 Radiological emergency

A radiological emergency may result:

- directly from a radiological incident; or
- indirectly from another emergency (for example a fire in an area that contains radiation sources).

Emergency response procedures should be initiated immediately for any emergency that is life threatening. As a minimum local area emergency response procedures should include instructions to:

- raise the alarm;
- get help (call emergency services, University emergency phone);
- make the area safe (if safe to do so);
- evacuate personnel from the area to a predetermined evacuation point; and
- contact the DRSO.

### 9.3 Recording reporting and investigation

All radiological incidents should be reported as soon as possible to the supervisor/manager and the DRSO. The DRSO shall contact the University RSA for assistance and advice. The University RSA shall notify the DH (as discussed in Section 9.1) of radiological incidents that must be reported.

#### Incidents and emergencies

All radiological incidents and emergencies should be reported as soon as possible to both the DRSO and the University Radiation Safety Adviser.

The *Health & Safety: Incident, injury and hazard reporting and investigation requirements* should be followed. This includes:

- entering the incident/emergency into ERMS (Enterprise Risk Management System); and
- initiating an incident investigation.

The manager/supervisor should ensure that the investigation includes input and assistance from the DRSO.

### 9.4 Incident and emergency procedures

Emergency procedures should be documented and available to all relevant staff and students at the time when ionising radiation sources are first purchased/used.

Emergency procedures should be reviewed at regular scheduled intervals. The length of time between reviews will depend on the level of risk associated with the activities undertaken. For example, a low risk activity may be scheduled for triennial reviews.

Emergency procedures may also require ad hoc review when there are:

- legislation changes;
- radiological incidents; and
- new information becomes available (such as additional risks associated with an isotope).

#### University procedures

Emergency procedures should take into the account the *Emergency Preparedness and Response Procedure*.

First aid procedures should consider the *Health & Safety: First aid requirements*.

As part of the local area induction, all staff and students should be briefed on the appropriate emergency procedures and reporting requirements.

Emergency procedures should include:

- local area emergency response;
- first aid requirements; and
- reporting and recording requirements (including the supervisor/manager and the DRSO).



Radiological emergencies that can be managed by a local area response (for example spilling an open source in a laboratory) have time to undertake the following:

- step back from the spillage;
- administer first aid if required;
- make the area safe;
- restrict access to the area;
- get assistance; and
- report the emergency as outlined in Section 9.3.

#### **Local area emergency response – Practical considerations**

The local area should have documented emergency procedures. Staff and students in the local area should be familiar with these procedures.

If an incident occurs – such as a spill – take time to implement the emergency procedure. Once you have stepped back from the incident you have time to consider what should happen next.

For example, if you think you are contaminated, don't leave the room but rather get assistance from others.

Take the time to let other people in the area know what has happened, such as signs.

Restrict access to the area.

You, your colleagues and the DRSO now have time to sit down and discuss the best way forward to deal with the incident.

## 9.5 Sourcing further information

Description of Information	Where to Obtain
University requirements: <ul style="list-style-type: none"><li>• <i>Health &amp; Safety: Incident, injury and hazard reporting and investigation requirements</i></li></ul>	<a href="https://safety.unimelb.edu.au/_data/assets/word_doc/0006/2077395/incident-injury-hazard-reporting-and-investigation-requirements.docx">https://safety.unimelb.edu.au/_data/assets/word_doc/0006/2077395/incident-injury-hazard-reporting-and-investigation-requirements.docx</a>
University requirements: <ul style="list-style-type: none"><li>• <i>Health &amp; Safety: First aid requirements</i></li></ul>	<a href="https://safety.unimelb.edu.au/_data/assets/pdf_file/0008/1832561/health-and-safety-first-aid-requirements.pdf">https://safety.unimelb.edu.au/_data/assets/pdf_file/0008/1832561/health-and-safety-first-aid-requirements.pdf</a>
University emergency preparedness and response	<a href="https://safety.unimelb.edu.au/emergency/emergency-response-and-preparedness">https://safety.unimelb.edu.au/emergency/emergency-response-and-preparedness</a>
The University First Aid	<a href="https://safety.unimelb.edu.au/hazard-topics/first-aid">https://safety.unimelb.edu.au/hazard-topics/first-aid</a>
Health & Safety Services radiation advice email address	<a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a>
DRSO contacts <ul style="list-style-type: none"><li>• Access Business Partner Contacts</li><li>• Navigate to relevant Academic Division</li></ul>	<a href="https://safety.unimelb.edu.au/people/community/local-contacts">https://safety.unimelb.edu.au/people/community/local-contacts</a>

## 9.6 References

Department of Health, 2017. *Mandatory reporting of radiation incidents*, Author, viewed 22 February 2021, <<https://www2.health.vic.gov.au/about/publications/policiesandguidelines/mandatory-reporting-radiation-incidents>>.

## 10 RADIOACTIVE WASTE MANAGEMENT

### 10.1 Introduction

When disposing of radiation sources all staff and students, must comply with the:

- *Disposal of radioactive material and x-ray equipment (Department of Health, 2017); and*
- *Health & Safety: Ionising radiation management plan.*

### 10.2 Disposing of radioactive waste

Radioactive waste normally refers to radioactive materials:

- open sources that are no longer in use and require removal/disposal; and
- closed sources that have decayed below legislative prescribed activity concentration (refer to Section 2.2.2).

The disposal method of radioactive waste is determined by:

- legal requirements,
- the physical properties of the source,
- the type of radiation emissions of the source; and
- the level of activity of the source.

The three controls for management waste are:

- dilution and dispersion;
- delay and decay; and
- concentration and containment.

#### NOTE:

Ensure that dilution and dispersion does not introduce other hazards (such as chemicals) into the environment.

#### 10.2.1 Dilution and dispersion

Dilution and dispersion enables short-lived or very dilute radioactive wastes to be diluted further until the waste is deemed to be non-radioactive. This can then be disposed of through appropriate waste streams.

#### 10.2.2 Delay and decay

Short-lived radiation sources can be stored and allowed to decay and until the waste is deemed to be non-radioactive. This can then be disposed of through the appropriate waste streams.

#### 10.2.3 Concentration and containment

Radiation sources with long half-lives require long term storage in a suitably built facility. This facility is managed by the central Health & Safety team.

### 10.3 University requirements

The University uses the categories described in Section 10.2 when disposing of radioactive wastes (open sources). Table 23 provides some examples of various radioactive open sources and how they are disposed of.

Local areas must have waste management procedures for the radioactive waste they generate. General waste management requirements are outlined in the *Health & Safety: Waste management requirements*.

Where staff and students are unsure of the appropriate waste strategy they should contact the DRSO for advice.

Advice may also be sought by contacting the Health & Safety team and the University RSA via the hazardous waste email or the radiation advice email.

Disposal Method	Examples	Description
Dilution and dispersion	$^{14}\text{C}$ When diluted to non-radioactive levels $^{14}\text{C}$ is disposed of through the University EPA waste contractor. $^3\text{H}$ When diluted to non-radioactive levels $^3\text{H}$ can be emptied down the sink.	University hazardous waste collection. A specialist contractor licensed by the Environmental Protection Agency (EPA). These collections are managed by Common Services, Occupational Health and Safety.
Delay and decay	$^{32}\text{P}$ and $^{33}\text{P}$ $^{32}\text{P}$ and $^{33}\text{P}$ can be stored at the local area until they have decayed to a non-radiological level. Length of decay will depend on both the half-life and the activity.	University hazardous waste collection. A specialist contractor licensed by the EPA. These collections are managed by Common Services, Occupational Health and Safety.
Concentration and containment	$^{137}\text{Cs}$ $^{137}\text{Cs}$ has a half-life of 30 years and is stored in an appropriately built location.	Arrangements by Common Services, Occupational Health and Safety Common Services, Occupational Health and Safety can be contacted to determine appropriate waste management of these.

Table 23: Disposal methods of radioactive waste management at the University

### 10.3.1 University hazardous waste collection

Waste that was radioactive can be included in the University hazardous waste collection after it has been signed off by the DRSO or their delegate. This will establish that the radioactive waste no longer meets the definition of a radioactive material as prescribed in the *Radiation Act 2005* (Vic).

Preparing waste that was radioactive for collection requires suitable packaging and labelling. The waste should be listed on the local area hazardous waste manifest. The information on the manifest will depend on the type of radioactive waste and generally includes:

- quantity (in kilos or litres);
- number of containers (the containers must be suitable for the waste); and
- type of radiation hazard.

Because the waste is below the legislative prescribed activity concentration, the radioactive label should be removed and the type of waste identified on the label (eg. biological, lead scrap metal etc.)

Local areas can access the hazardous waste collection service in several ways. Refer to the Hazardous Waste web page for more information:

<http://safety.unimelb.edu.au/safety-topics/hazardous-waste>

#### NOTE:

Remove all radioactive markings and symbols before placing the waste out for collection.

Label the waste so that it is clearly identifiable (eg chemical).

Select a suitable container that will hold the waste.

### 10.3.2 Containment of waste

Radioactive waste that requires concentration and containment is managed by the University RSA.

Local areas should contact their DRSO who will assess the radiological waste and prepare for local storage. Where required the DRSO will contact the University RSA who will plan for the removal of the radioactive waste.

## 10.4 Disposal of x-ray equipment

Radiation emitting apparatus such as an x-ray unit may require different disposal pathways from those previously discussed. The University RSA must be contacted where a radiation emitting apparatus requires disposal. The appropriate disposal method shall be determined on a case by case basis.

It is important to note that when an emitting apparatus is disposed of then:

- the DH must be notified, to remove the source from the licence; and
- the DRSO must be notified to update the local area inventory.

The University RSA shall provide the DH with details of the disposed radiation apparatus or sealed source apparatus.

#### Disposal of x-ray equipment

X-ray equipment must be rendered inoperable before disposal. The method of decommissioning will be determined by the type of x-ray equipment.

Older x-ray equipment may contain hazardous materials such as polychlorinated biphenyl (PCB).

Contact the University RSA for assistance.

[radiation-info@unimelb.edu.au](mailto:radiation-info@unimelb.edu.au)

## 10.5 Sourcing further information

Description of Information	Where to Obtain
University requirements: <ul style="list-style-type: none"> <li><i>Health &amp; Safety: Waste requirements</i></li> </ul>	<a href="https://safety.unimelb.edu.au/_data/assets/word_doc/0012/1798284/Health-and-safety-waste-management-requirements.docx">https://safety.unimelb.edu.au/_data/assets/word_doc/0012/1798284/Health-and-safety-waste-management-requirements.docx</a>
University requirements: <ul style="list-style-type: none"> <li><i>Health &amp; Safety: Chemical requirements</i></li> </ul>	<a href="https://safety.unimelb.edu.au/_data/assets/word_doc/0007/1805992/health-and-safety-chemical-requirements.docx">https://safety.unimelb.edu.au/_data/assets/word_doc/0007/1805992/health-and-safety-chemical-requirements.docx</a>
University requirements: <ul style="list-style-type: none"> <li><i>Health &amp; Safety: Ionising radiation requirements; and</i></li> <li><i>Health &amp; Safety: Ionising radiation management plan</i></li> </ul>	<a href="https://safety.unimelb.edu.au/safety-topics/radiation">https://safety.unimelb.edu.au/safety-topics/radiation</a>
Radiation advice email	<a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a>
Hazardous waste advice and collection email address	<a href="mailto:hazardouswaste-info@unimelb.edu.au">hazardouswaste-info@unimelb.edu.au</a>
DRSO contacts <ul style="list-style-type: none"> <li>Access Business Partner Contacts</li> </ul> Navigate to relevant Academic Division	<a href="https://safety.unimelb.edu.au/people/community/local-contacts">https://safety.unimelb.edu.au/people/community/local-contacts</a>
The University Hazardous Waste	<a href="http://safety.unimelb.edu.au/safety-topics/hazardous-waste">http://safety.unimelb.edu.au/safety-topics/hazardous-waste</a>
The <i>Health &amp; Safety: Chemical management guidelines</i>	<a href="https://safety.unimelb.edu.au/_data/assets/pdf_file/0010/1705906/chemical-management-guidelines.pdf">https://safety.unimelb.edu.au/_data/assets/pdf_file/0010/1705906/chemical-management-guidelines.pdf</a>

## 10.6 References

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 2020. *Guide for classification of radioactive waste, 2020*, Radiation Protection Series G-4, viewed 22 February 2021, <<https://www.arpansa.gov.au/regulation-and-licensing/regulatory-publications/radiation-protection-series/rps-g-4>>.

Department of Health, 2017. *Disposal of radioactive material and x-ray equipment*, Author, viewed 22 February 2021, <<https://www2.health.vic.gov.au/public-health/radiation/licensing/management-licenses-businesses/general-conditions/acquisition-disposal-relocation#:~:text=Many%20X%2Dray%20units%20can,of%20an%20X%2Dray%20unit.>>.

Victorian Government, 2019. *Radiation Act 2005*, Author, viewed 22 February 2021, <<https://www.legislation.vic.gov.au/in-force/acts/radiation-act-2005/032>>.



## 11 SUPERVISOR/MANAGER RESPONSIBILITIES

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### 11.1 Induction and training

The supervisor/manager has a responsibility for ensuring that staff and students under their supervision:

- receive an induction into the local area prior to commencing work; and
- undertake ionising radiation safety training applicable to their work activities and associated risks.

#### 11.1.1 Induction

The primary purpose of an induction is to ensure that staff and students in the local area are aware of the hazards and risks associated with:

- the activities they undertake;
- the activities others in the area undertake; and
- the environmental conditions of the local area.

Additionally, an induction provides students and staff with information regarding the local area such as:

- facilities;
- safety requirements and systems;
- safety staff (first aiders, wardens): and
- emergency procedures.

All staff and students should receive an induction prior to commencing work in the local area. As a minimum the induction should include:

- local area risk assessments that identify hazards, risks and controls;
- standard operating procedures that provide guidance on completing tasks safely;
- laboratory protocols that include safety requirements;
- suitable personal protective equipment (PPE) for the activities/tasks;
- requirements for personal radiation monitors and associated infrastructure;
- local area emergency requirements, including evacuation point, first aid kit, first aiders, emergency shower/eyewash;
- reporting and recording incident procedures; and
- DRSO introduction.

#### 11.1.2 Training

Staff and students who work with radiation sources require ionising radiation training prior to commencing work.

After identifying the ionising radiation training needs of staff and students, the supervisor/manager should ensure that this information is included on the local area training matrix.

After staff and students have completed ionising radiation training the supervisor/manager should ensure that a record of this training is kept. In relation to University staff, ionising radiation training is recorded in Themis. In relation to students (who are not on Themis) records are maintained by the department/local area.

## University training

Ionising radiation training at the University is developed and maintained by Health & Safety Services, Business Services.

The purpose of the training is to provide information on ionising radiation theory and requirements. The emphasis is on working safely with ionising radiation considering relevant University policy, requirements and processes.

Training is required for staff and students working with radiation sources and is available in TrainMe. There are two training modules available in TrainMe. Staff and students working with radiation sources are required to complete either training as follows:

- staff and students who do not have a use licence should complete *Safe radiation practices –Ionising*;
- staff and students who have a use licence should complete *Safe radiation practices –Use licence holders*.

For staff the training is available in TrainMe, accessed via the Staff Hub:

<https://staff.unimelb.edu.au/>

For students and staff the training is available in TrainMe via the Health & safety website:

<https://safety.unimelb.edu.au/#training>

Other specialist ionising radiation training is also available. This can be arranged through the radiation email: [radiation-info@unimelb.edu.au](mailto:radiation-info@unimelb.edu.au) and includes:

- Safe radiation practices – Neutron probe
- Safe radiation practices – Ionising (DEXA)
- Safe radiation practices – Departmental radiation safety officers
- Safe radiation practices – Iodine 131

A Certificate of completion (Table 25) may be required for some *use licence* applications and can be printed from TrainMe.



Figure 25: Certificate example

General training requirements are outlined in the *Health & Safety: Training requirements*.

## 11.2 Risk assessment

Risk assessment is the process of:

- determining the **hazards** to health and safety that exist for a task/activity, item or work environment;
- determining the importance of each hazard by assigning it a **risk rating** or **risk score**;
- formulating **risk control** measures that are reasonably practicable to apply, that will reduce the risk rating/score to an acceptable level (using the Hierarchy of Control); and
- documenting and **reviewing** all these matters (usually on a risk assessment template).

As identified hazards, assessed risks and controls associated with radiation sources should consider:

- the type, energy and activity of the ionising radiation;
- the dose rate; and
- the route of exposure.

### INCIDENTS AND EMERGENCIES:

It is important that risk assessments consider possible radiological incidents and emergencies.

Other non-radiological hazards associated with the radiation source or its containment should also be considered. This may include plant, electrical, chemical and so on.

The University uses a two-variable risk assessment methodology when assigning risk ratings to identified hazards.

Risk assessment requirements are outlined in the *Health & Safety: Risk management requirements*.

Risk assessments are entered and stored in the Enterprise Risk Management System (ERMS). A University username and password is required to access ERMS via [Staff Hub](#) or <https://www.riskcloud.net/prod/?ccode=uom>.

Where ERMS is unavailable risk assessment templates have been developed for radiation sources (Table 24).

Ionising Radiation	Risk Assessment Form
Radioactive material (open source)	<a href="#">Health &amp; Safety: Radioactive material risk assessment</a>
Radiation apparatus (eg x-ray unit)	<a href="#">Health &amp; Safety: Plant risk assessment</a>
Sealed source apparatus (eg fixed radiation gauge)	<a href="#">Health &amp; Safety: Plant risk assessment</a>
Sealed source (eg calibration sealed source)	<a href="#">Health &amp; Safety: Radioactive material risk assessment</a>
	Where corrective actions are required a Health & Safety: Action plan template can be used to prioritise and complete the actions <a href="#">Health &amp; Safety: Action plan</a>

Table 24: Risk assessment templates for use with radiation sources

### The hierarchy of control

The hierarchy of control is used to eliminate or manage radiation risks to as low a level as practicable (using ALARA). These are listed below in order of effectiveness.

#### Elimination

Eliminate/remove the requirement to use a radiation source.

#### Substitution

Replace the radiation source with a less hazardous form. Replace an open source with a shorter half-life, less energy and lower biological impact.

#### Engineering Controls:

Engineering the solution to minimise risk the risk of exposure to a radiation source

- Redesign the way in which work is performed, modify equipment to change the way a task is performed or engineer change to the process steps to eliminate hazardous activity. One may also completely automate a process where there is minimal or no human interaction.
- Isolate a radiation hazard by physically shielding, enclosing, adding ventilation or restricting access to eliminate/reduce risk.

#### Administration Controls:

Administration controls are the procedural aspects of managing hazards, such as issuing OSL monitors, planned and preventative maintenance programs, standard operating procedures, education and training and the rotation of staff thus minimising exposure.

#### Personal Protective Equipment (PPE):

PPE is the last and least effective control method used. It may involve staff and students wearing appropriate gloves and laboratory coats whilst working with open isotopes.

**Note:** Refer to the controls to prevent external exposure and internal exposure (Section 6.3 and Section 6.4) for the additional guidance.

## 11.3 Standard operating procedure

A standard operating procedure (SOP) should be developed for activities that use radiation sources. The SOP should consider the identified risks and the required controls outlined in the risk assessment.

The *Health & Safety: Risk management requirements* outline the following requirements when developing an SOP:

- staff and students in consultation with supervisors/managers, shall develop SOPs or health and safety work instructions for specific tasks or operations;
- supervisor/managers shall ensure SOPs or health and safety work instructions contain suitable document control; and
- supervisor/managers can use the University SOP form for SOPs or health and safety work instructions.

### INCIDENTS AND EMERGENCIES:

It is important that standard operating consider possible radiological incidents and emergencies.

## 11.4 Purchasing

### 11.4.1 New radiation sources

A radiation source cannot be acquired by a local area unless both the location and the intended activity are listed on the *management licence*. When a local area needs to acquire a new radiation source certain information is required. This information is passed on to the DH for approval and the addition of the activity and location on the licence.

As well as applying for a new radiation source to be added to the *management licence*, a Pre-purchase checklist should be completed.

Prior to purchase the University RSA must be notified so that:

- arrangements to add the radiation source to the University Radiation Management can commence; and
- guidance and advice can be provided where required.

The local area can confirm with the University RSA what information is required. This can be done through the radiation email: [radiation-info@unimelb.edu.au](mailto:radiation-info@unimelb.edu.au)

Advice can also be given with regards to Use Licencing where applicable.

#### New radiation sources

Supervisors/managers considering the purchase of new radiation sources should contact the University Radiation Safety Adviser as soon as practicable. New radiation sources can have complex considerations and requirements that require careful preplanning and arrangements.

### 11.4.2 Complete a pre-purchase checklist

A [Health & Safety: Pre-purchase checklist](#) addresses several considerations prior to purchasing new radiation sources including:

- the likelihood of new or additional hazards/risks because of the purchase; and
- the controls required to eliminate or mitigate potential risks.

For all initial purchases, the Authorising Officer (employee with delegated authority to permit the purchase of goods and services) shall ensure a Health and Safety: Pre-Purchase checklist has been completed prior to the authorising the purchase.

Pre-purchase requirements are outlined in the *Health & Safety: Purchasing requirements*.

### 11.4.3 Notifying the DRSO

Prior to purchase the local area DRSO should be notified so that they can:

- add the radiation source to the local area inventory;
- provide guidance where required; and
- work with the University RSA as required

### 11.4.4 Ongoing radiation sources

Local areas have pre-existing arrangements in place to enable the ongoing purchase of radiation sources that are listed on the *management licence*. These arrangements may include:

- ordering the radiation source through iProcurement
- contacting the DRSO to arrange purchase;
- contacting the University RSA to arrange purchase; or
- a combination of the above.

## 11.5 Transport

Transportation refers to the movement of radiation sources via road, rail, air or sea. The legal requirements around transportation of radiation sources is both highly regulated and complex.

Managers/supervisors are not expected to be fully familiar with transportation requirements. Managers/supervisors should seek advice where transportation of radiation sources is required.

With regards to transport attention should be paid to:

- legal requirements;
  - packaging;
  - labelling;
  - placarding;
- University requirements;
  - spill kits;
  - emergency procedures;
    - signed off by the manager/supervisor and the DRSO;
    - include instructions for damaged or lost radiation sources.

### 11.5.1 Packaging

Packaging of radiation sources for transport is designed to protect the contents from both expected handling conditions and unexpected incidents.

There are specifications and limitations on the type of packaging used in the transport of radiation sources. The type of package depends on the activity and type of the radiation source transported. Packaging requirements are outlined in the *Australian code for the transport of dangerous goods by road & rail* (Cth), known as the ADG and include:

- Excepted package;
- Industrial package Type 1 (Type IP-1);
- Industrial package Type 2 (Type IP-2);
- Industrial package Type 3 (Type IP-3);
- Type A package;
- Type B(U) package;
- Type B(M) package; and
- Type C package.

### 11.5.2 Excepted packaging

Excepted packaging, refers to packaged radiation sources where the activity at any point on the external surface of the package does not exceed 5  $\mu\text{Sv/h}$ .

Importantly this reduces the transport requirements associated with radiation sources. This includes a licenced contractor is not required to transport radiation sources in excepted packages.

Excepted packages only require the marking “RADIOACTIVE” on an internal surface so that the presence of a radiation source is visible on opening the package.

The label on the outside of the package (Figure 26) indicates the presence of a radiation source without the tri-foil symbol.

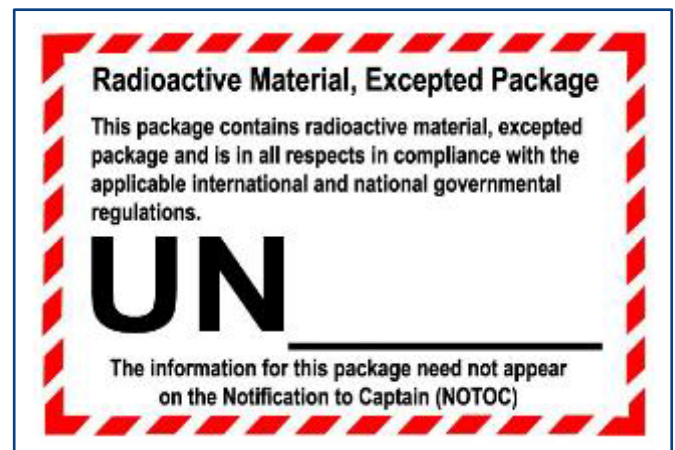


Figure 26: Excepted package label

### Open Sources

Open sources should be sealed and placed in the centre of the package and surround by an absorbent product such vermiculite. Ideally if the original packaging is available this should be used. The package should be sealed and the appropriate label affixed.

### Emergency Procedures

Emergency procedures should be documented and available with the package and include:

- spill kit;
- instructions on emergency response; and
- emergency contact numbers.

### 11.5.3 Labelling

Apart from excepted packages, packages must be labelled with category I-White, II-Yellow or III-Yellow labels, depending on the content of radiation source and the level of activity at the surface of the package (Figure 27).

A category I-White label means that the radiation activity at the surface of the package is very low. A category III-Yellow label means that the package has the highest accessible radiation activity at the surface of the package and in its near vicinity.

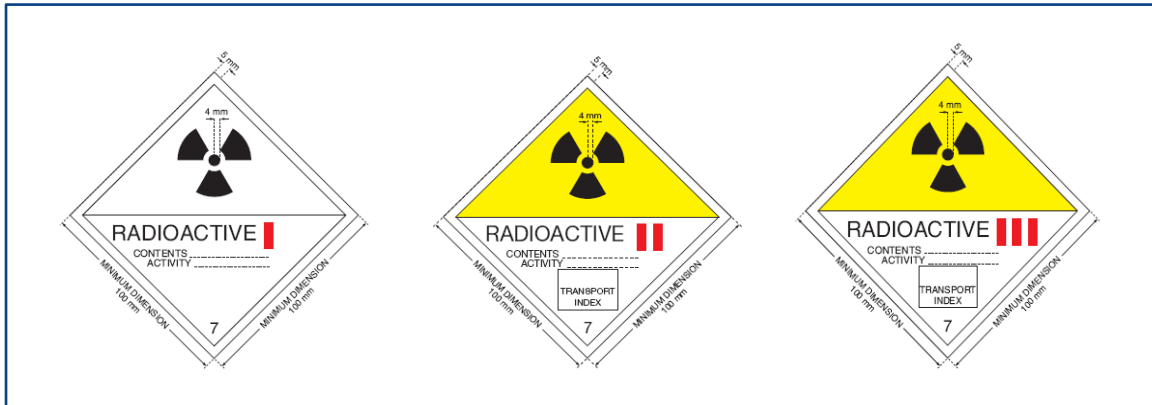


Figure 27: Radioactive packaging labelling during transport

### 11.5.4 Placarding



Figure 28: Class 7 dangerous good placard

Placarding refers to a sign that is affixed to a vehicle. As with labelling, there are specific legal requirements relation to placarding.

The ADG determines the symbol, size and layout of a Class 7 placard (Figure 28). In Victoria, transport of dangerous goods and placarding requirements are regulated by the *Dangerous Goods (Transport by Road or Rail) Regulations 2008* (Vic). The Regulations require placarding arrangements as per the ADG.

#### Transport of a radiation source

Where a radiation source requires transporting by a licenced contractor a [Consignment declaration for the transport of radioactive material](#) (ARPANSA, 2019) must be completed.

The supervisor/manager can contact the DRSO and/or the University RSA for advice.

Email: [radiation-info@unimelb.edu.au](mailto:radiation-info@unimelb.edu.au)



## 11.6 Sourcing further information

Description of Information	Where to Obtain
<b>11.1 Induction and training</b> University requirement: <ul style="list-style-type: none"> <li><i>Health &amp; Safety: Training requirements</i></li> </ul>	<a href="https://safety.unimelb.edu.au/_data/assets/word_doc/0007/2077585/health-and-safety-training-requirements.docx">https://safety.unimelb.edu.au/_data/assets/word_doc/0007/2077585/health-and-safety-training-requirements.docx</a>
University training	<a href="http://safety.unimelb.edu.au/#training">http://safety.unimelb.edu.au/#training</a>
<b>11.2 Risk assessment</b> University requirement: <ul style="list-style-type: none"> <li><i>Health &amp; Safety: Risk management requirements</i></li> </ul>	<a href="https://safety.unimelb.edu.au/_data/assets/pdf_file/0007/2080744/health-and-safety-risk-management-requirements.pdf">https://safety.unimelb.edu.au/_data/assets/pdf_file/0007/2080744/health-and-safety-risk-management-requirements.pdf</a>
Enterprise Risk Management System	Access via Staff Hub: <a href="https://staff.unimelb.edu.au/">https://staff.unimelb.edu.au/</a> or <a href="https://www.riskcloud.net/prod/?ccode=uom">https://www.riskcloud.net/prod/?ccode=uom</a>
University risk assessment process risk assessment templates	<a href="http://safety.unimelb.edu.au/management/implement">http://safety.unimelb.edu.au/management/implement</a>
<b>11.3 Standard operating procedures</b> Health & Safety: Standard operating procedure (SOP) form	<a href="https://safety.unimelb.edu.au/_data/assets/word_doc/0004/1836130/standard-operating-procedure-form.docx">https://safety.unimelb.edu.au/_data/assets/word_doc/0004/1836130/standard-operating-procedure-form.docx</a>
<b>11.4 Purchasing</b> University requirement <ul style="list-style-type: none"> <li><i>Health &amp; Safety: Purchasing requirements</i></li> </ul>	<a href="https://safety.unimelb.edu.au/_data/assets/word_doc/0011/1806887/health-and-safety-purchasing-requirements.docx">https://safety.unimelb.edu.au/_data/assets/word_doc/0011/1806887/health-and-safety-purchasing-requirements.docx</a>
<b>11.5 Transport</b> <ul style="list-style-type: none"> <li><i>Code for the safe transport of radioactive material. RPS C-2</i></li> </ul>	<a href="https://www.arpana.gov.au/regulation-and-licensing/regulatory-publications/radiation-protection-series/codes-and-standards/rpsc-2">https://www.arpana.gov.au/regulation-and-licensing/regulatory-publications/radiation-protection-series/codes-and-standards/rpsc-2</a>
DRSO contacts <ul style="list-style-type: none"> <li>Access Business Partner Contacts</li> <li>Navigate to relevant Academic Division</li> </ul>	<a href="https://safety.unimelb.edu.au/people/community/local-contacts">https://safety.unimelb.edu.au/people/community/local-contacts</a>

## 11.7 References

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 2019. *Consignment Declaration for the transport of radioactive material*, Australian Government, viewed 22 February 2021, <[https://www.arpansa.gov.au/sites/default/files/consignor\\_dec\\_form.pdf](https://www.arpansa.gov.au/sites/default/files/consignor_dec_form.pdf)>.

Australian Government, 2007. *Australian code for the transport of dangerous goods by road & rail, (ADG)*, 7.7<sup>th</sup> edn., National Transport Commission, viewed 22 February 2021 <<https://www.ntc.gov.au/codes-and-guidelines/australian-dangerous-goods-code>>.

Victorian Government, 2018. *Dangerous Goods (Transport by Road or Rail) Regulations 2018*, Author, viewed 22 February 2021 <<https://www.legislation.vic.gov.au/in-force/statutory-rules/dangerous-goods-transport-road-or-rail-regulations-2018/001>>.

## 12 LABORATORY CERTIFICATION

### 12.1 Description

Laboratories using ionising radiation require University ionising radiation laboratory certification. The purpose of this certification is to ensure that the laboratory:

- complies with legal requirements;
- complies with University requirements; and
- adopts the radiation protection principles when undertaking ionising radiation activities.

The program is undertaken as self- certification process by radiation laboratory staff and/or the DRSO. The University RSA audits a sample number of laboratories annually. Records of certification are maintained centrally by Health & Safety Services, Business Services.

Certification is repeated biennially.

On completion of certification a *laboratory certification* (Figure 29) sticker is issued which can be attached near or on the doorway into the laboratory.



Figure 29: Laboratory certification

### 12.2 Process

The certification process covers five categories including:

- management;
- laboratory practices;
- training;
- incident reporting and emergency procedures; and
- ionising radiation and sealed sources.

To undertake ionising radiation self-certification the local area needs to complete a [Health & Safety: Ionising radiation laboratory certification checklist](#).

Forward to the University RSA: [radiation-info@unimelb.edu.au](mailto:radiation-info@unimelb.edu.au)

#### 12.2.1 Management

Management systems include:

- controlled authorised access to laboratory/area
- ionising radiation signs
- completed risk assessments and standard operating procedures
- staff and students personal monitoring (where applicable)
- tag out system in place
- suitable PPE available and used
- sources are listed on *Radiation inventory* (or equivalent)
- purchasing approvals given

### 12.2.2 Laboratory practices

Laboratory practices include:

- radiation/contamination monitoring equipment available
- equipment calibration
- storage of ionising radiation
- labelling
- controls that reduce dose
- personal monitoring available
- authorised users list
- segregation of radioactive activities
- disposal pathways for radiation sources

### 12.2.3 Training

Training requirements include:

- laboratory inductions completed for all staff and students
- appropriate radiation safety training

### 12.2.4 Incident reporting and emergency procedures

Incident reporting and emergency procedures include:

- emergency procedures in place
- staff and students aware of emergency procedures
- incident reporting procedures in place

### 12.2.5 Emitting apparatus and sealed sources

Emitting apparatus and sealed sources requirements include:

- ionising equipment appropriately housed
- visible and audible (if applicable) warning signs
- fail-to-safe mechanisms to prevent exposure
- fail-to-safe mechanisms regularly checked
- scheduled radiation apparatus surveys
- room design (including structure) considers shielding requirements
- risk assessments for emitting apparatus

## 12.3 Sourcing further information

Description of Information	Where to Obtain
University radiation certification	<a href="http://safety.unimelb.edu.au/hazard-topics/radiation">http://safety.unimelb.edu.au/hazard-topics/radiation</a>
University RSA	<a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a>
Health & Safety radiation advice email address	<a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a>
DRSO contacts <ul style="list-style-type: none"><li>Access Business Partner Contacts</li><li>Navigate to relevant Academic Division</li></ul>	<a href="https://safety.unimelb.edu.au/people/community/local-contacts">https://safety.unimelb.edu.au/people/community/local-contacts</a>
University conditions and obligations: <ul style="list-style-type: none"><li><i>Health &amp; Safety: Ionising radiation requirements; and</i></li><li><i>Health &amp; Safety: Ionising radiation management plan</i></li></ul>	<a href="http://safety.unimelb.edu.au/hazard-topics/radiation">http://safety.unimelb.edu.au/hazard-topics/radiation</a>

## 13 FURTHER ADVICE AND ASSISTANCE

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### 13.1 University key contacts and assistance

Staff and students have several key resources at the University that they can contact for assistance with their ionising radiation enquiries. These include:

- Departmental Radiation Safety Officers
- University Radiation Safety Adviser
- Health & Safety Services, Business Services

#### 13.1.1 Department Radiation Safety Officer

The DRSO is the local area contact appointed by the Head of Department to assist with the implementation and management of the University ionising radiation requirements. The DRSO should be the initial point of contact.

Contacts details are linked to the University Business Partner Contacts. Then navigate to the relevant Academic Division address is:

<https://safety.unimelb.edu.au/people/community/local-contacts>

#### 13.1.2 Staff Services Portal (ServiceNow)

For all radiation enquires to Health & Safety Services, Business Services (including the University RSA) log into the staff hub, access ServiceNow and select “Health & Safety”.

#### 13.1.3 University Radiation Safety Adviser

The University RSA provides expert advice and assistance with regards to ionising radiation. Currently this position is held by Steve Guggenheimer. The contact details are:

[radiation-info@unimelb.edu.au](mailto:radiation-info@unimelb.edu.au)

#### 13.1.4 Health & Safety Services, Business Services

Health & Safety Services, Business Services carry out several important functions with regards to ionising radiation including:

- maintaining the *management licence*;
- mandating and maintaining the University ionising radiation requirements;
- providing ionising radiation training; and
- providing ionising radiation advice.

The contact email is:

[radiation-info@unimelb.edu.au](mailto:radiation-info@unimelb.edu.au)

## 14 LIST OF ABBREVIATIONS

<b>ADG</b>	<i>Australian code for the transport of dangerous goods by road &amp; rail, 7<sup>th</sup> edn.</i> , National Transport Commission
<b>ALARA</b>	As low as reasonably achievable
<b>ANSTO</b>	Australian Nuclear Science and Technology Organisation
<b>ARPANSA</b>	Australian Radiation Protection and Nuclear Safety Association
<b>AS</b>	Australian Standard
<b>ASNO</b>	Australian Safeguards and Non-Proliferation Office
<b>CPM</b>	Counts per minute
<b>CPS</b>	Counts per second
<b>DH</b>	Department of Health & Human Services
<b>DRSO</b>	Departmental Radiation Safety Officer
<b>DPS</b>	Disintegrations per second
<b>EMR</b>	Electromagnetic radiation
<b>EPA</b>	Environmental Protection Authority
<b>ERSC</b>	Electromagnetic Radiation Safety Committee
<b>HREC</b>	Human Research and Ethics Committee
<b>HVL</b>	Half-value layer
<b>IAEA</b>	International Atomic Energy Agency
<b>ICRP</b>	International Commission of Radiological Protection
<b>ISO</b>	International Organization for Standardization
<b>LLE</b>	Loss of life expectancy
<b>NHMRC</b>	National Health and Medical Research Council
<b>OSL</b>	Optically stimulated luminescence
<b>PPE</b>	Personal Protective Equipment
<b>RSA</b>	Radiation Safety Advisor
<b>SDS</b>	Safety data sheet
<b>SI</b>	(Système Internationale) International System of Units
<b>SOP</b>	Standard Operating Procedure
<b>TLD</b>	Thermoluminescent Dosimetry
<b>TVL</b>	Tenth-value layer



## 15 APPENDIX A: PROPERTIES OF COMMONLY USED RADIONUCLIDES

The following has been adapted from Standards Association of Australia AS 2243.4: Safety in laboratories. Part 4. Ionizing radiations. (Appeared in AS 2243.4 1998. Removed from AS 2243.4 20180.

Nuclide	Radiotoxicity group +	Radiological half-life	Biological half-life	Max. energy of main beta rays MeV (% abundance)	Main gamma ray energy MeV (% abundance) ‡	Gamma ray constant μSv/h §	Most restrictive occupational inhalation ALI Bq	Occupational DAC (Note 1) Bq/m <sup>3</sup>
H-3 (gas)	4						1.1×10 <sup>13</sup>	4.6×10 <sup>9</sup>
H-3 (water Vapour)	4	12.3y	10d	0.018	---	---	7.7×10 <sup>7</sup>	3.2×10 <sup>4</sup>
H-3 (organically bound)	4						4.9×10 <sup>8</sup>	2.0×10 <sup>5</sup>
C-11	4						---	---
C-11 (vapour)	4	20.38m		0.96 (98%)	0.511 (200%)	194	1.7×10 <sup>10</sup>	6.9×10 <sup>6</sup>
C-11 monoxide	4			(positrons)			9.1×10 <sup>9</sup>	3.8×10 <sup>6</sup>
C-11 dioxide	4						6.3×10 <sup>9</sup>	2.6×10 <sup>6</sup>
C-14	4						---	---
C-14 (vapour)	4	5730y	12d	0.156 (100%)	---	---	3.4×10 <sup>7</sup>	1×10 <sup>7</sup>
C-14 monoxide	4						2.5×10 <sup>10</sup>	38×10 <sup>6</sup>
C-14 dioxide	4						9.1×10 <sup>9</sup>	1.4×10 <sup>4</sup>
N-13		9.97m		1.190 (100%)	0.511 (200%)	194	---	---
O-15		2.04m		1.7 (100%) positrons	0.511 (200%)	194	---	---
F-18	4	1.83h	6h	0.635 (97%) positrons	0.511 (193%)	188	2.2×10 <sup>8</sup>	9.0×10 <sup>4</sup>
Na-22	3b	2.6y	11d	0.540 (89%) positrons	0.511 (180%) 1.270 (100%)	360	1.0×10 <sup>7</sup>	4.2×10 <sup>3</sup>
Na24	3b	15h		1.390 (99.9%)	1.37 (100%) 2.750 (100%)	520	3.8×10 <sup>7</sup>	1.6×10 <sup>4</sup>

Nuclide	Radiotoxicity group +	Radiological half-life	Biological half-life	Max. energy of main beta rays MeV (% abundance)	Main gamma ray energy MeV (% abundance) ‡	Gamma ray constant µSv/h §	Most restrictive occupational inhalation ALI Bq	Occupational DAC (Note 1) Bq/m³
P-32	3a	14.3d	257d	1.700 (100%)	---	---	69×10 <sup>6</sup>	2.9×10 <sup>3</sup>
P-33	3b	25.4d	257d	0.249 (100%)	---	---	15×10 <sup>7</sup>	6.4×10 <sup>3</sup>
S-35 (inorganic)	3b	87d	90d	0.167 (100%)	---	---	1.8×10 <sup>7</sup>	7.6×10 <sup>3</sup>
S-35 (org. bound gas/vapour)							1.7×10 <sup>8</sup>	6.9×10 <sup>3</sup>
K-42	4	12.4h		3.52 (82%) 2.0 (18%)	1.520 (18%)	39	1.0×10 <sup>8</sup>	4.2×10 <sup>4</sup>
Ca-45	3a	163d	45y	0.260 (99.9%)			8.7×10 <sup>6</sup>	3.6×10 <sup>3</sup>
Ca-47	3a	4.54d		0.690 (82%) 1.990 (18%)	1.300 (75%)	160	9.5×10 <sup>6</sup>	4.0×10 <sup>3</sup>
Sc-47	3b	3.351d		0.440 (68%) 0.601 (32%)	0.159 (68%)	22 6.3	2.7×10 <sup>7</sup>	1.1×10 <sup>4</sup>
Cr-51	4	27.7d	616d				5.6×10 <sup>8</sup>	2.3×10 <sup>5</sup>
Fe-55	3b	2.7y	2000d	0.005 (16%)			2.2×10 <sup>7</sup>	9.1×10 <sup>3</sup>
Fe-59	3a	45d	700d	0.470 (53%) 0.270 (46%)	1.100 (57%) 1.290 (43%)	180	6.3×10 <sup>6</sup>	2.6×10 <sup>3</sup>
Co-57	3b	271d	9.5d	---	0.122 (86%) 0.136 (10%)	41	3.3×10 <sup>7</sup>	1.4×10 <sup>4</sup>
Co-58	3b	71d	9.5d	0.475 (14.8%) (positrons)	0.511 (29.8%) 0.810 (99%)	170	1.2×10 <sup>7</sup>	4.9×10 <sup>3</sup>
Co-60	3	2.53y	9.5d	0.318 (100%)	1.170 (100%) 1.330 (100%)	370	1.2×10 <sup>6</sup>	4.9×10 <sup>2</sup>
Cu-64	4	12.58h		0.578 (37%)	0.511 (35.7%)	36	1.3×10 <sup>8</sup>	5.6×10 <sup>4</sup>

Nuclide	Radiotoxicity group +	Radiological half-life	Biological half-life	Max. energy of main beta rays MeV (% abundance)	Main gamma ray energy MeV (% abundance) ‡	Gamma ray constant µSv/h §	Most restrictive occupational inhalation ALI Bq	Occupational DAC (Note 1) Bq/m³
				0.653 (18%) (positrons)				
Cu-67	3b	61.7h	3.78d	0.390 (56%)	0.090 (17%)	24	3.4×10 <sup>7</sup>	1.4×10 <sup>4</sup>
Zn-65	3a	244d	933d	---	1.115 (50.7%)	89	7.1×10 <sup>6</sup>	3.0×10 <sup>3</sup>
Ga-67	3b	3.26d		---	0.093 (35.7%)	30	7.1×10 <sup>7</sup>	3.0×10 <sup>4</sup>
Ga-68	4	67.7m	6d	1.900 (88%)	0.511 (178%)	179	1.5×10 <sup>8</sup>	1.0×10 <sup>5</sup>
Ge-68	2	288d		---	0.020 (67.7%)	16	2.5×10 <sup>6</sup>	1.1×10 <sup>3</sup>
Se-75	3b	119.8d		---	0.265 (59.8%)	230	1.2×10 <sup>7</sup>	4.9×10 <sup>3</sup>
					0.62 (43%) 0.70 (28%) 0.93 (24%) 1.04 (27%) 1.32 (27%) 1.48 (16%)			
Br-82	3b	1.47d		0.444 (98%)		440	2.3×10 <sup>7</sup>	9.5×10 <sup>3</sup>
Rb-86	3b	18.7d	45d	0.697 (8.8%) 1.774 (91.2%)	---	15	1.5×10 <sup>7</sup>	6.4×10 <sup>3</sup>
Sr-89	3a	50.5d	1.8 x 10 <sup>4</sup> d	1.49 (100%)	---	---	3.6×10 <sup>6</sup>	1.5×10 <sup>3</sup>
Sr-90	2	29y	50y	2.280 (Note 2)	---	---	2.6×10 <sup>5</sup>	1.1×10 <sup>2</sup>
Y-90	3b	2.67d	49y	.280 (100%)	---	---	1.2×10 <sup>7</sup>	4.9×10 <sup>3</sup>
Mo-99	3b	2.8d		0.436 (17%) 1.210 (83%)	0.74 (13%)	31	1.8×10 <sup>7</sup>	7.6×10 <sup>3</sup>
Tc-99m	4	6.0h	20d	---	0.14 (89%)	33	6.9×10 <sup>8</sup>	2.9×10 <sup>5</sup>
Cd-109	2	462d	9000d	---		50	2.1×10 <sup>6</sup>	8.7×10 <sup>2</sup>
In-111	3b	2.8d	Indefinite	---	0.245 (94%)	140	6.5×10 <sup>7</sup>	2.7×10 <sup>4</sup>

Nuclide	Radiotoxicity group +	Radiological half-life	Biological half-life	Max. energy of main beta rays MeV (% abundance)	Main gamma ray energy MeV (% abundance) ‡	Gamma ray constant µSv/h §	Most restrictive occupational inhalation ALI Bq	Occupational DAC (Note 1) Bq/m³
					0.171 (90%)			
I-123	4	13.2h	138d	---	0.159(83.4%)	75	1.8×10 <sup>8</sup>	7.6×10 <sup>4</sup>
					0.027 (30%)			
I-124	3a	4.18d		---	0.511 (46%)	205	3.2×10 <sup>6</sup>	1.3×10 <sup>3</sup>
					0.603 (59%)			
I-125	2	60d	138d		0.027 (39%)	74	2.7×10 <sup>6</sup>	1.1×10 <sup>3</sup>
I-131	2	8d	138d	0.610 (89%)	0.360 (81.2%)	77	1.8×10 <sup>6</sup>	7.6×10 <sup>2</sup>
I-132	4	2.3h		1.185 (18.9%)	0.670 (98.7%)	390	1.0×10 <sup>8</sup>	4.2×10 <sup>4</sup>
Cs-131	4	9.7d		---	34	4.4×10 <sup>8</sup>	1.9×10 <sup>5</sup>	3.4×10 <sup>8</sup>
Cs-137	3a	30y	70d	0.510 (94.6%)	0.660 (Note 2)	103 (Note 2)	3.0×10 <sup>6</sup>	1.2×10 <sup>3</sup>
				0.690 (43%)				
Sm-153	3b	46.7h		0.640 (35%)	0.103 (28%)	24	2.9×10 <sup>7</sup>	1.2×10 <sup>4</sup>
				1.19 (14%)				
Dy-165	4	2.33h		1.29 (83%)	---	6.2	2.3×10 <sup>8</sup>	9.6×10 <sup>4</sup>
Yb-169	3a	32.0d		---	0.590 (35%)	88	8.3×10 <sup>6</sup>	3.5×10 <sup>3</sup>
				0.540 (41%)	0.320 (82.8%)			
Ir-192	3a	74d	20d	0.670 (48%)	0.468 (48%)	160	4.1×10 <sup>6</sup>	1.7×10 <sup>3</sup>
Au-198	3b	2.7d	120d	0.960 (98.8%)	0.410 (95.5%)	79	1.8×10 <sup>7</sup>	7.6×10 <sup>3</sup>
Tl-201	4	3.04d		---	0.167 (10%)	24	2.6×10 <sup>8</sup>	1.1×10 <sup>5</sup>
Ra-226	2	1600y	1.64 x 10 <sup>4</sup> d	---	---	3.2	9.1×10 <sup>3</sup>	3.8×100
					0.0139 (42.7%)			
Am-241	1	432y	50y	---	0.060 (35.9%)	85	7.4×10 <sup>2</sup>	3.1×10 <sup>-1</sup>

## Mixtures

Nuclide	Radiotoxicity group +	Radiological half-life	Biological half-life	Max. energy of main beta rays MeV (% abundance)	Main gamma ray energy MeV (% abundance) ‡	Gamma ray constant µSv/h §	Most restrictive occupational inhalation ALI Bq	Occupational DAC (Note 1) Bq/m³
Sr-90+Y-90	2	29y	49y	2.28	---	---	5.1×10 <sup>5</sup>	2.1×10 <sup>2</sup>
Ra-226+d (Note 3)	2	1600y		3.27 (Note 2)	0.8 (Note 4)	223	5.0×10 <sup>4</sup>	2.1×10 <sup>1</sup>
Th metal (freshly chemically separated thorium – Th-232 + Th-228)	4	1.4×10 <sup>10</sup> y				6.6×10 <sup>2</sup>	2.7×10 <sup>-1</sup>	1.3×10 <sup>5</sup>
Th-ore (Note 5)	4	--		0.04	0.24		3.1×10 <sup>3</sup>	1.3×10 <sup>0</sup>
				0.33	0.58		(Note 7)	
				1.28	0.910	340		
				1.52	0.97	(Note 6)		
				1.80	2.61			
				2.25				
U metal (freshly chemically separated uranium – U-238 + U-234)	4	4.5×10 <sup>9</sup> y		3.2×10 <sup>3</sup>	1.3×10 <sup>0</sup>	4.3×10 <sup>5</sup>		
U-ore (Note 5)	4	---		0.02	0.05			
				0.06	0.13			
				0.19	0.30			
				0.67	0.35			
				0.73	0.61	150	3.5×10 <sup>3</sup>	1.5×10 <sup>0</sup>
				1.51	0.80	(Note 8)		
				1.54	1.12			
				2.28	1.76			
				3.27				

## SYMBOLS:

- \* Values in this Table have been rounded. Values for radionuclides not included in this document may be obtained from the regulatory authority.
- + Radio toxicity groups are based on data from *ICRP Publication 68* (ICRP, 1994).
- ‡ These data should not be used for shielding calculations as only gammas with greater than 10% abundance are listed. Other gamma rays or x-rays may be present.
- § Data derived from *The health physics and radiological handbook* (Shleien, 1992).

These ALI values are based on *ICRP Publication 68* (ICRP, 1994). Revised ingestion dose coefficients have been published in *ICRP Publication 56* (ICRP, 1990), *ICRP Publication 69* (ICRP, 1995). The data used in these calculations are ICRP default values; where site-specific data are available they may be used instead.

## NOTES:

- 1 Based on 5 µm AMAD aerosol and a breathing rate of 2400 m<sup>3</sup> per year.
- 2 Decay product radiation.
- 3 Together with decay products down to Pb-210.
- 4 Mean effective energy with 0.5 mm Pt-Ir encapsulation.
- 5 With all decay products present.
- 6 Per GBq of Th-232 with all decay products present. If thoron and its immediate short-lived decay products are not present, divide by 4.
- 7 For U-ore and Th-ore, activities are total becquerels. To convert to an activity, multiply by 0.6.
- 8 Per GBq of U-238 with all decay products present. If radon and its immediate short-lived decay products are not present, divide by 20.

## REFERENCES:

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- Shleien B (Ed). *The health physics and radiological health handbook*, Silver Spring, MD, USA: Senita Inc., Revised edition, 1992.