About This Booklet

This booklet is used in conjunction with the Ionising Radiation Risk Management Procedure and the Safe Radiation Practices training materials.

The authors of this text 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 this training guide is used.

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1 INTRODUCTION

1.1 THE MANAGEMENT GUIDE

This management guide has been written for The University of Melbourne (UoM) personnel undertaking work involving ionising radiation.

The management guide is intended to be used in conjunction with the UoM ionising radiation activities and the in-house training series Safe Radiation Practices

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 Röntgen1 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.

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

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.

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

An x-ray of the hand requires an exposure of about 1/25 to 1/50 of a second today.

1 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) show a number of these advances in radiation physics, radiobiology and radiotherapy from 1895 to 1950 (Figure 2).

![Figure 2: Time line – Advances in radiation physics, radiobiology and radiotherapy 1895 to 1950 (Bernier, Hall and Giaccia, 2004)](image-url)
1.3 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
</table>
| Radiation oncology: a century of achievements (Bernier, Hall & Giaccia, 2004) | Instructions:  
| The full journal article is available from the UoM e-journals. It is accessed through the UoM library. | |

1.4 REFERENCES

2 LEGAL REQUIREMENTS

There are numerous Acts, Regulations, Standards and Codes that oversee the regulation 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 GOVERNMENT

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 (Australian Government, 1998); and

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


The Nuclear Non-Proliferation (Safeguards) 1987 Act (Australian Government, 1987) has specific storage, security and reporting requirements for radioactive sealed sources that have been identified as possible use in illegal activities.

2.2 VICTORIAN GOVERNMENT – IONISING RADIATION LEGISLATION

2.2.1 Introduction

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

- Radiation Amendment Act 2013 (Victorian Government, 2013); and

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

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

Radiation legislation also requires:

- all personnel working with radiation sources be individually licensed (Use Licence) – there may be exemptions granted under certain conditions;
- all personnel working with radiation sources be appropriately trained to the nature of tasks undertaken; and
- all laboratories with radiation sources to comply with the applicable legislative requirements.
2.2.2 Legal Definition of Radioactive Material

Regulation 5(a)(b) of the Radiation Regulations 2007 (Victorian Government, 2007a) defines radioactive material as follows:

(a) the prescribed activity concentration for a material that is a radionuclide specified in column one 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 one of Schedule 1 is the activity specified in column 3 of that Schedule opposite that radionuclide.

<table>
<thead>
<tr>
<th>Legal Definition of Radioactive Material Simplified</th>
</tr>
</thead>
</table>

2.2.3 Radiation Source

The Radiation Amendment Act 2013 (Victorian Government, 2013) defines a radiation source to mean:

- radioactive material;
- radiation apparatus; or
- sealed source apparatus.

A radioactive material spontaneously emits radiation and is normally described as an open or closed source.

A radiation apparatus produces radiation when activated, such as an x-ray machine.

A sealed source apparatus contains radioactive material that is fully encapsulated, such as a soil moisture/density probe.

<table>
<thead>
<tr>
<th>Day-To-Day Practical Application of Radiation Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>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. On the other hand ionising radiation apparatus do not have a “half-life” and therefore whilst there may be disposal issues they won’t be because of radiological waste.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Open Sources</th>
<th>Closed Sources</th>
<th>Ionising Radiation Apparatus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examples</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^3$H, $^{14}$C, $^{35}$S, $^{32}$P, $^{33}$P, $^{125}$I</td>
<td>$^{60}$Co, $^{137}$Cs, $^{68}$Ge</td>
<td>X-ray machines, Linear accelerators, Cyclotrons, Fluoroscopy</td>
</tr>
<tr>
<td>Advantages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used in small quantities</td>
<td>No Internal contamination</td>
<td>No Half-life concerns</td>
</tr>
<tr>
<td>Easy to shield</td>
<td></td>
<td>No Waste disposal problems</td>
</tr>
<tr>
<td>Disadvantages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half life</td>
<td>Potential Large Dose</td>
<td>Potential Large Dose</td>
</tr>
<tr>
<td>Spills</td>
<td>Half life</td>
<td>Shielding</td>
</tr>
<tr>
<td>Internal contamination</td>
<td>Shielding</td>
<td>Security</td>
</tr>
<tr>
<td>Waste disposal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biological areas</td>
<td>Physical Sciences</td>
<td>Medical research</td>
</tr>
<tr>
<td>Medical research</td>
<td>Industrial areas</td>
<td>Physical Sciences</td>
</tr>
</tbody>
</table>
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 2007* (Victorian Government, 2007a).

The dose limits are based on advice from *The 2007 Recommendations of the International Commission of Radiological Protection (ICRP, 2007)*. In Australia these recommendations have been incorporated into the *National Standard for Limiting Occupational Exposure to Ionizing Radiation, [NOHSC:1013(1995)]* (ARPANSA, 2002).

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

<table>
<thead>
<tr>
<th>Application</th>
<th>Occupational Dose limit</th>
<th>Public Dose limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>effective dose²</td>
<td>20 mSv per year, averaged over a period of 5 consecutive</td>
<td>1 mSv in a year</td>
</tr>
<tr>
<td></td>
<td>calendar years</td>
<td></td>
</tr>
<tr>
<td>lens of the eye</td>
<td>150 mSv</td>
<td>15 mSv</td>
</tr>
<tr>
<td>skin</td>
<td>500 mSv</td>
<td>50 mSv</td>
</tr>
<tr>
<td>hands and feet</td>
<td>500 mSv</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Dose limits mandated by the *Radiation Regulations 2007* (Victorian Government, 2007a)

2.2.5 Licensing

The *Radiation Amendment Act 2013* (Victorian Government, 2013) 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 Amendment Act 2013* (Victorian Government, 2013) requires a person or organisation to hold a radiation Management Licence for the possession, sale 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 Department of Health.

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 Department of Health (2012a) has published information regarding the holder of a radiation Management Licence mandatory responsibilities. In particular the mandatory obligations discussed include:

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

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² Effective dose is defined in Section 4.8.6.
Schedules

The Management Licence is divided into “schedules” that distinguish radiation sources and their uses into 10 sections (Table 2).

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The general conditions which apply to the entire licence</td>
</tr>
<tr>
<td>2</td>
<td>Radiation practices involving ionising radiation apparatus</td>
</tr>
<tr>
<td>3</td>
<td>Radiation practices involving sealed source apparatus</td>
</tr>
<tr>
<td>4</td>
<td>Radiation practices involving sealed sources</td>
</tr>
<tr>
<td>5</td>
<td>Radiation practices involving radioactive material</td>
</tr>
<tr>
<td>6</td>
<td>Radiation practices involving procuring, arranging or conducting research involving irradiation of persons</td>
</tr>
<tr>
<td>7</td>
<td>Radiation practices involving non-ionising radiation sources</td>
</tr>
<tr>
<td>8</td>
<td>Radiation practices involving sale of radiation sources</td>
</tr>
<tr>
<td>9</td>
<td>Radiation practices involving transport of radioactive material</td>
</tr>
<tr>
<td>10</td>
<td>List of radiation sources which the licence holder has notified as being in their possession</td>
</tr>
</tbody>
</table>

Table 2: Radiation 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 Department of Health 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 personnel at the UoM are discussed in Section 3.2.3.

2.2.8 Ionising Radiation Research on Participants (People)

The Department of Health categorise ionising radiation on participants (living people) as:
- the radiation dose to participants does not exceed the effective does limit; or
- the radiation does to participants does exceed the effective dose limit.

The effective dose limit is defined in Table 1 of the Code of Practice Exposure of Humans to Ionizing Radiation for Research Purposes RPS NO 8 (ARPANSA, 2005).

Researchers should refer to Section 4. Use of Ionising Radiation Guidelines (Department of Health, 2012c).

2.3 Victorian Government – Safety Legislation

Victorian safety legislation is administered by WorkSafe and includes:
- Occupational Health and Safety Act 2004 (Victorian Government, 2004); and

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 personnel 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.

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 Standards for consideration by the Commonwealth, States and Territories.

ARPANSA publishes and/or maintains the following publications.
1. The Radiation Protection Series (RPS) of publications.
   These publications replace the Radiation Health Series, formerly published by National Health and Medical Research Council (NHMRC).
2. The Radiation Health Series (RHS) of publications.
   Formerly published by the NHMRC and currently being maintained and reviewed by ARPANSA.

There are four different publications associated with the Radiation Protection Series. These include:
- Radiation Protection Standards;
- Codes of Practice;
- Recommendations; and
- Safety Guides.

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 worldwide 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 (2010) 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.”

2.5 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Commonwealth Resources (AustLII, 2011)</td>
<td></td>
</tr>
<tr>
<td>• Victorian Legislation and Parliamentary Documents (Victorian Government, nd)</td>
<td>Select the “Victorian Law Today” icon in the web link</td>
</tr>
<tr>
<td>Exemptions from use licence requirements (Department of Health, 2011b)</td>
<td><a href="http://docs.health.vic.gov.au/docs/doc/Exemptions-from-use-licence-requirements">http://docs.health.vic.gov.au/docs/doc/Exemptions-from-use-licence-requirements</a></td>
</tr>
<tr>
<td>ICRP publications</td>
<td><a href="http://www.icrp.org/publications.asp">http://www.icrp.org/publications.asp</a></td>
</tr>
<tr>
<td>IAEA home page</td>
<td><a href="http://www.iaea.org/">http://www.iaea.org/</a></td>
</tr>
<tr>
<td>IAEA publications</td>
<td><a href="http://www.iaea.org/Publications/index.html">http://www.iaea.org/Publications/index.html</a></td>
</tr>
<tr>
<td>Australian Standards (administered through SAI Global). The UoM has a subscription to the Standards. They can be accessed through the UoM library Discovery search. A UoM user name and password is required.</td>
<td>Instructions: 1. Log-on to the UoM library Discovery search from the library home page. Link: <a href="http://www.library.unimelb.edu.au/">http://www.library.unimelb.edu.au/</a>  2. Select “Find Database” and access the Standards through SAI Global – Australian Standards.</td>
</tr>
</tbody>
</table>

2.6 REFERENCES


3 UNIVERSITY OF MELBOURNE REQUIREMENTS

The UoM must comply with the legal requirements discussed in the previous section. Therefore the UoM has developed policy and procedures to ensure that it complies with both Commonwealth and State legal requirements and provide a safe and healthy environment for all personnel working with radiation sources.

3.1 POLICY AND PROCEDURE

The UoM occupational health and safety (OHS) ionising radiation requirements are described in the:
- Ionising Radiation Risk Management Procedure; and
- Ionising Radiation Management Plan.

The Director, OHS and Injury Management is responsible for developing, publishing and maintaining the procedure and the plan.

3.2 LICENSING

3.2.1 Management Licence

The radiation Management Licence is centrally controlled and maintained by the UoM Radiation Safety Adviser on behalf of the Director, OHS and Injury Management. This includes:
- maintaining an inventory of all radiation sources used by the UoM; and
- providing the Department of Health with mandated information where there are modifications to the current licence such as:
  - acquisition of radiation sources; and
  - disposal of radiation sources.

It is the responsibility of the local area to:
- maintain an inventory of their radiation sources; and
- provide this radiation inventory to the UoM Radiation Safety Adviser.

Due to the breadth of ionising radiation activities undertaken at the UoM, there are seven schedules relevant to the UoM radiation Management Licence (Table 3). Each schedule in the Management Licence has specific mandated conditions. These include complying with:
- radiation legislation;
- Department of Health directives;
- ARPANSA Radiation Protection Series publications; and
- Radiation Health Series publications.

These conditions have been included in Table 3 against their corresponding schedules.
The National standard for limiting occupational exposure to ionizing radiation, [NOHSC:1013(1995)] *Radiation Protection Series Publication No. 1, (ARPANSA, 2002)*, is not included in the UoM radiation Management Licence. Nevertheless the publication is referred to in all ARPANSA Radiation Protection Series Publications and therefore is considered, by the UoM as a general condition of the UoM radiation Management Licence.

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Description</th>
<th>Conditions</th>
</tr>
</thead>
</table>
| 1        | The general conditions | • *Disposal of radioactive material* (Department of Health, 2011)  
• *Mandatory reporting of radiation incidents* (Department of Health, 2012a) |
| 2        | Radiation practices involving ionising radiation apparatus |  
X-ray analysis unit (incorporating an x-ray unit) | • *Code of practice for protection against ionizing radiation emitted from x-ray analysis equipment, Radiation Health Series No. 9* (NHMRC, 1984) |
<p>|          | Cabinet x-ray unit (baggage scanner) | • <em>Revised statement on cabinet x-ray equipment for examination of letters, packages, baggage, freight and other articles for security, quality control and other purposes 1987, Radiation Health Series No. 21</em> (NHMRC, 1987) |
|          | Particle accelerator | • <em>Mandatory radiation safety requirements</em> (Department of Health, 2012b) |
|          | Dentistry – Dental intra-oral x-ray unit | • <em>Mandatory radiation safety requirements</em> (Department of Health, 2012b) |
|          | Dentistry – Dental intra-cephalometric and/or panoramic x-ray unit | • <em>Code of practice radiation protection in dentistry 2005, Radiation Protection Series Publication No. 10</em> (ARPANSA, 2005a) |
|          | Medical – Computed tomography unit | • <em>Mandatory radiation safety requirements</em> (Department of Health, 2012b) |</p>
<table>
<thead>
<tr>
<th>Schedule</th>
<th>Description</th>
<th>Conditions</th>
</tr>
</thead>
</table>
| Radiation source-procuring, arranging or conducting research involving irradiation of persons | | Code of practice for the exposure of humans to ionizing radiation for research purposes 2005, Radiation Protection Series Publication No. 8 (ARPANS, 2005b)  
Also referred to in RPS Publication No. 8 is: National statement on ethical conduct in research involving humans (NHMRC, 2007) |

3 Radiation practices involving sealed source apparatus

| Fixed x-ray analysis unit (incorporating a sealed source) | | Code of practice for protection against ionizing radiation emitted from x-ray analysis equipment, Radiation Health Series No. 9 (NHMRC, 1984) |
Also referred to in RPS Publication 5 is: Code of practice for the safe transport of radioactive material 2008, Radiation Protection Series Publication No. 2 (ARPANSA, 2008b) |

4 Radiation practices involving sealed sources

| Education and research not involving the exposure of humans to ionising radiation | | Mandatory radiation safety requirements (Department of Health, 2012b) |

5 Radiation practices involving radioactive material

| Education and research not involving the exposure of humans to ionising radiation | | Mandatory radiation safety requirements (Department of Health, 2012b) |

6 Radiation practices involving procuring, arranging or conducting research involving irradiation of persons

| Research involving the exposure of humans to ionising radiation | | Code of practice for the exposure of humans to ionizing radiation for research purposes 2005, Radiation Protection Series Publication No. 8 (ARPANSA, 2005b)  
Also referred to in RPS Publication No. 8 is: National statement on ethical conduct in research involving humans (NHMRC, 2007) |

10 List of the radiation sources which the licence holder (UoM) has stated as being in their possession.

It is the responsibility of local areas to ensure that systems are in place to meet the conditions of the radiation Management Licence.
Modifying the Radiation Management Licence

Modifying the radiation 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:
• update the radiation inventory to reflect the modified radiation sources; and
• provide this updated inventory to the UoM Radiation Safety Adviser.

3.2.2 Use Licence

All ionising radiation qualifications and licensing requirements are maintained by the local area. Therefore it is the local area’s responsibility to:
• ensure personnel have the appropriate training;
• ensure personnel have a current Use Licence prior to using a radioactive source;
• ensure that the Use Licence includes the proposed radioactive source and activity; and
• maintain a current record of all personnel Use Licences.

What do I need to include in my application for a licence – use? (Department of Health, 2013) outlines the specified purposes and/or occupations and the specified types of radiation sources requiring a Use Licence.

3.2.3 Exemptions

The Department of Health (Victorian Government, 2011) has gazetted exemptions for a person to hold a Use Licence. In most cases these exemptions include:
• staff who are training with regards to the radiation source or working towards a particular 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.

In the above exemptions both staff and students require supervision from a person who has an appropriate Use Licence.

Staff that use radioactive material (open isotopes) for the purpose of conducting laboratory tests are also exempt from a Use Licence.

Note
It is an offence under the Radiation Amendment Act 2013 for a local area to use a radiation source that is not listed against their location on the UoM radiation Management Licence.

Note
It is an offence under the Radiation Amendment Act 2013 for a person to use a radiation source without a Use Licence (unless exempted) or in a manner that is not included on the Use Licence.
3.3 RESPONSIBILITIES

Within areas controlled by the UoM where a radiation source is used, a clearly defined chain of responsibility shall be specified with the duties and responsibilities of individual persons clearly set out in writing.

The Head of Department/School is responsible for providing and maintaining resources necessary to comply with the Management Licence, the Ionising Risk Management Procedure and implement the Ionising Radiation Management Plan.

3.3.1 Manager/Supervisor

The manager/supervisor must protect personnel from radiation sources by:

- complying with the conditions of the Management Licence, Codes of Practice, Standards and the UoM procedures;
- providing a safe place of work, including the radiation protection principles (justification, optimisation and limitation);
- ensuring all safety procedures are followed;
- ensuring training is undertaken by all personnel prior to working with radiation sources;
- providing appropriate personal monitoring equipment to all personnel working with radiation sources;
- ensuring all radiation monitoring equipment is maintained and calibrated as required;
- ensuring all sources of radiation are regularly checked and maintained as per the conditions of the Management Licence; and
- ensuring records required by the Department of Health are maintained and available.

3.3.2 University of Melbourne Radiation Safety Adviser

The University of Melbourne Radiation Safety Adviser is responsible for:

- providing guidance to the Head of Department/School on the appointment of a Departmental Radiation Safety Officers (DRSO);
- providing advice on safe working practices, including storage, waste and transport in accordance with relevant legislation, Codes of Practice and Standards;
- providing support to DRSOs;
- liaising with the relevant regulatory authorities;
- ensuring that the UoM radiation Management Licence is maintained;
- undertaking inspections, and providing reports and recommendations to local areas;
- investigating and reporting “radiological incidents” to the regulatory authority;
- providing guidance on emergency procedures; and
- providing ionising radiation training.

3.3.3 Departmental Radiation Safety Officer

The Head of Department/School, taking into account guidance from the UoM Radiation Safety Adviser, is responsible for appointing the Departmental Radiation Safety Officer (DRSO). The DRSO is responsible for:

- liaising with the Radiation Safety Adviser on local area radiation requirements;
- providing advice on safe working practices, including storage, waste and transport in accordance with relevant legislation, Codes of Practice and Standards;
- liaising with managers/supervisors;
- providing information to the UoM Radiation Safety Adviser on changes to local area radiation activities that may affect licensing;
- arranging for local area radiation monitoring;
- assisting managers/supervisors with ensuring that monitoring equipment is fit for purpose and calibrated;
- providing guidance on emergency procedures for possible radiological incidents;
- reporting radiological incidents to the Radiation Safety Adviser; and
- maintaining local area dose records.

---

3 Refer to Section 9.1 for an explanation of a radiological incident.
3.3.4 Personnel

Personnel (staff, students and others) are required to observe all local safe working instructions. In particular, all personnel working with ionising radiation shall apply the radiation protection principles (justification, optimisation and limitation).

In addition personnel are responsible for:
- using personal monitoring devices (thermoluminescent dosimetry badge or other) where provided;
- reporting immediately to the supervisor/manager and/or DRSO any instance of unsafe practice or other hazardous situation;
- understanding the biological, chemical and/or physical properties of radiation sources being used;
- reducing to a minimum the radiation hazards in the workplace;
- complying with relevant sections of legislation, Codes of Practices and Standards; and
- complying with local area instructions, such as risk assessments, standard operating procedures and emergency procedures.

3.4 Electromagnetic Radiation Safety Committee

The Electromagnetic Radiation Safety Committee (ERSC) comprising twelve members, 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 of Melbourne;
- 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 quarterly;
- review and/or amend the Terms of Reference; and
- provide minutes to the Director, OHS and Injury Management to be tabled at the Occupational Health and Safety Committee (OHSC).

3.5 UoM Dose Limits

UoM policy requires that ionising radiation activities, where reasonably practicable, undertaken at the UoM shall limit total whole body exposure to no more than that of a member of the public. These dose limits have been adopted to take into account:
- pregnant staff or students; and
- students that may be under 18 years of age.

Adopting an effective dose limit of 1 mSv annually encourages best practice.

Note

UoM policy requires that ionising radiation activities, where reasonably practicable, undertaken at the UoM shall limit total whole body exposure to no more than that of a member of the public.

This means the effective dose limit at the University of Melbourne is:

1 mSv annually
3.6 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Melbourne procedures:</td>
<td></td>
</tr>
<tr>
<td>• Ionising Radiation Management Plan</td>
<td></td>
</tr>
<tr>
<td>What do I need to include in my application for a licence – use? (Department of Health, 2013)</td>
<td><a href="http://docs.health.vic.gov.au/docs/doc/Prerequisites-for-applying-for-use-licences">http://docs.health.vic.gov.au/docs/doc/Prerequisites-for-applying-for-use-licences</a></td>
</tr>
<tr>
<td>Common Services, Occupational Health and Safety advice, information and guidance on ionising radiation practices within the UoM</td>
<td><a href="http://safety.unimelb.edu.au/topics/radiation/">http://safety.unimelb.edu.au/topics/radiation/</a></td>
</tr>
<tr>
<td>Electromagnetic Radiation Safety Committee web page:</td>
<td></td>
</tr>
<tr>
<td>• meeting calendar</td>
<td><a href="http://safety.unimelb.edu.au/consultation/committees/electromagnetic/">http://safety.unimelb.edu.au/consultation/committees/electromagnetic/</a></td>
</tr>
<tr>
<td>• membership</td>
<td></td>
</tr>
<tr>
<td>• minutes</td>
<td></td>
</tr>
<tr>
<td>• Terms of Reference</td>
<td></td>
</tr>
<tr>
<td>Common Services, Occupational Health and Safety radiation advice email address</td>
<td><a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a></td>
</tr>
<tr>
<td>Departmental Radiation Safety Officer contacts list</td>
<td><a href="http://safety.unimelb.edu.au/topics/radiation/drso/">http://safety.unimelb.edu.au/topics/radiation/drso/</a></td>
</tr>
</tbody>
</table>

3.7 REFERENCES


4 IONISING RADIATION

4.1 THE 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 3): 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 $1.6726 \times 10^{-27}$ kg and $1.6749 \times 10^{-27}$ kg respectively.

The electron has a mass approximately 1800 times smaller than protons and neutrons of $9.11 \times 10^{-31}$ kg.

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 4) 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 5). 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.


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.

There are two types of EMR that are ionising. These are:
- x-rays; and
- gamma rays.

The electromagnetic spectrum represents the entire range of frequencies of EMR (Figure 6). 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 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.

The speed of light is 299,792,458 meters per second or $2.9979258 \times 10^8$ m/s in a vacuum.

**Gamma rays**

Gamma rays, like x-rays, are invisible; carry no charge and travel at the speed of light. Their wavelengths are generally shorter than x-rays having wavelengths below 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). Generally speaking protons are not emitted alone but are combined with neutrons (Figure 7).

![Figure 7: Particulate radiation](image)

**Alpha particles**

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 electrons that are negatively or positively charged (positron). Electrons are fundamental particles or leptons 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.

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

Neutrons

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.

4.3.3 In Summary

In summary, various properties of the different types of ionising radiation can be compared (Table 4).

<table>
<thead>
<tr>
<th>Type of Radiation</th>
<th>Symbol</th>
<th>Electrical Charge</th>
<th>Penetration</th>
<th>Ionising Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>alpha (helium nuclei)</td>
<td>α</td>
<td>+ + charge</td>
<td>short</td>
<td>strong</td>
</tr>
<tr>
<td>beta (electrons)</td>
<td>β</td>
<td>– charge</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>neutron (neutrons)</td>
<td>n</td>
<td>no charge</td>
<td>short to high</td>
<td>weak to strong</td>
</tr>
<tr>
<td>Gamma</td>
<td>γ</td>
<td>no charge</td>
<td>High</td>
<td>weak</td>
</tr>
<tr>
<td>X-ray</td>
<td>X</td>
<td>no charge</td>
<td>High</td>
<td>weak</td>
</tr>
</tbody>
</table>

Table 4: Summary of properties of the types of ionising radiation

4.4 Penetration Properties

The penetrating properties of the ionising radiation are dependent on the:

- type of radiation (Figure 8);
- activity of the source; and
- level of energy.

4.4.1 Type of Radiation

Alpha Radiation

Alpha particles are highly charged and will quickly ionise with whatever they come into contact with. 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.
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.

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.

4.4.2 Activity of Source

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

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

4.4.3 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.

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

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

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\(^4\) 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.

There is a preference to use only a small number of SI prefixes when quantifying the amount and describing the properties of ionising radiation (Table 5). In particular:
- G (giga; \(10^9\));
- M (mega; \(10^6\));
- m (milli; \(10^{-3}\)); and
- µ (micro; \(10^{-6}\)).

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>(10^n)</th>
<th>Decimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>peta</td>
<td>P</td>
<td>(10^{15})</td>
<td>1,000,000,000,000,000</td>
</tr>
<tr>
<td>terra</td>
<td>T</td>
<td>(10^{12})</td>
<td>1,000,000,000,000</td>
</tr>
<tr>
<td>giga</td>
<td>G</td>
<td>(10^9)</td>
<td>1,000,000,000</td>
</tr>
<tr>
<td>mega</td>
<td>M</td>
<td>(10^6)</td>
<td>1,000,000</td>
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<tr>
<td>kilo</td>
<td>k</td>
<td>(10^3)</td>
<td>1,000</td>
</tr>
<tr>
<td>milli</td>
<td>m</td>
<td>(10^{-3})</td>
<td>0.001</td>
</tr>
<tr>
<td>micro</td>
<td>µ</td>
<td>(10^{-6})</td>
<td>0.000001</td>
</tr>
<tr>
<td>nano</td>
<td>n</td>
<td>(10^{-9})</td>
<td>0.000000001</td>
</tr>
<tr>
<td>pico</td>
<td>p</td>
<td>(10^{-12})</td>
<td>0.00000000001</td>
</tr>
</tbody>
</table>

Table 5: 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 \(^{238}\text{U}\).
However it is not unusual 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.

Different nomenclature variations can be found throughout this training guide. For differing examples refer to the isotopes in:

- Appendix A; and
- Figure 10.

### 4.8 MEASURING RADIATION

#### 4.8.1 Activity

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

A becquerel is defined as:

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

A curie is defined as 37 billion disintegrations per second.

In 1975 the becquerel replaced the curie (Ci) as the SI unit of radioactivity.

It is a legal requirement in Victoria for manufacturers and suppliers to express radioactivity in becquerel, however units expressed in curie are still supplied. This is particularly true for those imported from North America. Therefore it is useful to know the conversion of curie to becquerel (Table 6).

<table>
<thead>
<tr>
<th>Curie (Ci)</th>
<th>Becquerel (Bq)</th>
<th>dps</th>
<th>cpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$3.7 \times 10^{10}$</td>
<td>$3.7 \times 10^{10}$</td>
<td>$2.22 \times 10^{12}$</td>
</tr>
<tr>
<td>0.1 (100 mCi)</td>
<td>$3.7 \times 10^8$</td>
<td>$3.7 \times 10^8$</td>
<td>$2.22 \times 10^{11}$</td>
</tr>
<tr>
<td>0.01 (10 mCi)</td>
<td>$3.7 \times 10^6$</td>
<td>$3.7 \times 10^6$</td>
<td>$2.22 \times 10^{10}$</td>
</tr>
<tr>
<td>0.001 (1 mCi)</td>
<td>$3.7 \times 10^4$</td>
<td>$3.7 \times 10^4$</td>
<td>$2.22 \times 10^9$</td>
</tr>
<tr>
<td>0.0001 (100 μCi)</td>
<td>$3.7 \times 10^2$</td>
<td>$3.7 \times 10^2$</td>
<td>$2.22 \times 10^8$</td>
</tr>
</tbody>
</table>

Table 6: Conversion of curie to becquerel

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

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

Radiological activity is present in our everyday environment and a comparison of different substances assists in answering that question (Table 7).
### Table 7: Examples of radiological activity in the everyday environment

<table>
<thead>
<tr>
<th>Substance</th>
<th>Becquerel (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kg of granite</td>
<td>1000</td>
</tr>
<tr>
<td>1 kg of coffee</td>
<td>1000</td>
</tr>
<tr>
<td>1 kg of coal ash</td>
<td>2000</td>
</tr>
<tr>
<td>100 m² of air in an Australian home (radon)</td>
<td>3000</td>
</tr>
<tr>
<td>1 kg super phosphate fertiliser</td>
<td>5000</td>
</tr>
<tr>
<td>1 adult human</td>
<td>7000</td>
</tr>
<tr>
<td>100 m² of air in an European home</td>
<td>30,000</td>
</tr>
<tr>
<td>1 household smoke detector</td>
<td>30,000</td>
</tr>
<tr>
<td>1 kg uranium ore (Australian, 0.3%)</td>
<td>500,000</td>
</tr>
<tr>
<td>1 kg low level radioactive waste</td>
<td>1 million</td>
</tr>
<tr>
<td>1 kg uranium</td>
<td>25 million</td>
</tr>
<tr>
<td>1 radioisotope source for medical diagnosis</td>
<td>70 million</td>
</tr>
<tr>
<td>1 luminous exit sign (1970s)</td>
<td>1,000,000 million</td>
</tr>
<tr>
<td>1 kg 50-year old vitrified high-level nuclear waste</td>
<td>10,000,000 million</td>
</tr>
<tr>
<td>1 radioisotope source for medical therapy</td>
<td>100,000,000 million</td>
</tr>
</tbody>
</table>

### 4.8.2 Electron Volt

An electron volt is the kinetic energy gained by an electron passing through a potential difference of one volt in a vacuum. This can be expressed as one volt (or one joule per coulomb) multiplied by an electron charge (Figure 9).

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 9: A unit of energy equal to the energy an electron gains by being accelerated across an electric potential of 1 volt in a vacuum](image)

### 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.

The roentgen (R) is defined as the quantity of gamma ray or x-ray radiation required to produce one electrostatic unit of electricity of either sign per cubic centimetre of dry air. A drawback of radiological energy is that it 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.

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 calculated.

### 4.8.4 Absorbed Dose

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 equivalent dose evaluates the likelihood of harm from the absorbed dose on a biological tissue (humans).

There is a complicating issue when applying the absorbed dose to a biological system. This is because the absorbed dose for different types of radiations causes varying degrees of damage on biological tissue. Therefore a radiation weighting factor\(^5\) \((W_R)\) is taken into account for both the type and the energy of the radiation (Table 8).

<table>
<thead>
<tr>
<th>Particle/Photon</th>
<th>Radiation Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutrons &lt;10 keV</td>
<td>5</td>
</tr>
<tr>
<td>Neutrons 10 keV – 100 keV</td>
<td>10</td>
</tr>
<tr>
<td>Neutrons 100 keV – 2 MeV</td>
<td>20</td>
</tr>
<tr>
<td>Neutrons 2 MeV – 20 MeV</td>
<td>10</td>
</tr>
<tr>
<td>Neutrons &gt; 20 MeV</td>
<td>5</td>
</tr>
<tr>
<td>Alpha Particles</td>
<td>20</td>
</tr>
<tr>
<td>Beta Particles</td>
<td>1</td>
</tr>
<tr>
<td>X – Rays</td>
<td>1</td>
</tr>
<tr>
<td>Gamma Rays</td>
<td>1</td>
</tr>
<tr>
<td>Protons</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 8: The radiation weighting factors for different types of ionising radiation

\(^5\) The radiation weighting factor is also referred to as the radiation quality factor.
The radiation weighting factor is determined by the International Commission on Radiological Protection ICRP Publication 60 (ICRP, 1991).

The equivalent dose is determined by the following equation:

\[ H = D \times W_R \]

\( H = \) equivalent dose \hspace{1cm} \( D = \) average absorbed dose in the organ \hspace{1cm} \( W_R = \) radiation weighting factor

<table>
<thead>
<tr>
<th>Organ and Tissues</th>
<th>Tissue Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>gonads</td>
<td>0.20</td>
</tr>
<tr>
<td>bone marrow</td>
<td>0.12</td>
</tr>
<tr>
<td>colon</td>
<td>0.12</td>
</tr>
<tr>
<td>lungs</td>
<td>0.12</td>
</tr>
<tr>
<td>stomach</td>
<td>0.12</td>
</tr>
<tr>
<td>bladder</td>
<td>0.05</td>
</tr>
<tr>
<td>breast</td>
<td>0.05</td>
</tr>
<tr>
<td>liver</td>
<td>0.05</td>
</tr>
<tr>
<td>oesophagus</td>
<td>0.05</td>
</tr>
<tr>
<td>thyroid</td>
<td>0.05</td>
</tr>
<tr>
<td>skin</td>
<td>0.01</td>
</tr>
<tr>
<td>bony surfaces</td>
<td>0.01</td>
</tr>
<tr>
<td>other</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Total (Whole Body)</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>

Table 9: Former tissue weighting factors (ICRP, 1991)

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 Effective Dose

Different organs/tissues in the human body will have varying degrees of sensitivity to ionising radiation. Therefore the 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 (Table 10).

ICRP Publication 60 (ICRP, 1991) lists former tissue weighting factors for the various parts of the body (Table 9). The former tissue weighting factors have been included in the training notes because they are still referenced.
The current tissue weighting factors (Table 10) and are listed in ICRP Publication 103 (ICRP, 2007).

<table>
<thead>
<tr>
<th>Organs and Tissues</th>
<th>Tissue Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>gonads</td>
<td>0.08</td>
</tr>
<tr>
<td>bone marrow</td>
<td>0.12</td>
</tr>
<tr>
<td>colon</td>
<td>0.12</td>
</tr>
<tr>
<td>lungs</td>
<td>0.12</td>
</tr>
<tr>
<td>stomach</td>
<td>0.12</td>
</tr>
<tr>
<td>bladder</td>
<td>0.04</td>
</tr>
<tr>
<td>breast</td>
<td>0.12</td>
</tr>
<tr>
<td>liver</td>
<td>0.04</td>
</tr>
<tr>
<td>oesophagus</td>
<td>0.04</td>
</tr>
<tr>
<td>thyroid</td>
<td>0.04</td>
</tr>
<tr>
<td>skin</td>
<td>0.01</td>
</tr>
<tr>
<td>bony surfaces</td>
<td>0.01</td>
</tr>
<tr>
<td>salivary glands</td>
<td>0.01</td>
</tr>
<tr>
<td>brain</td>
<td>0.01</td>
</tr>
<tr>
<td>other</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Total (Whole Body)</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>

Table 10: Revised tissue weighting factors (ICRP, 2007)

The effective dose is determined by the following equation:

\[ E = H \times W_T \]

E = effective dose  \quad H = equivalent dose  \quad 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: \[ E = 2 \times 0.12 = 0.24 \text{ mSv} \]

For the thyroid \[ E = 1 \times 0.04 = 0.04 \text{ mSv} \]

The effective dose \(0.25 + 0.04 = 0.29 \text{ mSv}\)

**Leading to a problem with 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.

**4.8.7 Dose Rate**

Dose rate is the amount of radiation that is received over a period of time. When detected with a portable Geiger counter it is normally expressed in Sv per hour.
4.8.8 Summary of Radiation Units

Radiation SI units can be summarised and compared to the old radiation units (Table 11).

<table>
<thead>
<tr>
<th>Type</th>
<th>SI Unit</th>
<th>Symbol</th>
<th>Old Unit</th>
<th>Symbol</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>exposure (Photons only)</td>
<td>coulomb per kilogram</td>
<td>C/kg</td>
<td>roentgen</td>
<td>R</td>
<td>1C/kg = 3876 R</td>
</tr>
<tr>
<td>absorbed dose</td>
<td>gray</td>
<td>Gy</td>
<td>rad</td>
<td>r</td>
<td>1Gy = 100 r</td>
</tr>
<tr>
<td>equivalent dose</td>
<td>sievert</td>
<td>Sv</td>
<td>rem⁶</td>
<td>rem</td>
<td>1Sv = 100 rem</td>
</tr>
<tr>
<td>effective dose</td>
<td>sievert</td>
<td>Sv</td>
<td>rem</td>
<td>rem/h</td>
<td>1Sv/h = 100 rem/h</td>
</tr>
<tr>
<td>dose rate</td>
<td>sievert per hour</td>
<td>Sv/h</td>
<td>rem per hour</td>
<td>rem/h</td>
<td></td>
</tr>
</tbody>
</table>

Table 11: 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, 238U (Uranium 238) has an unstable nucleus. Due to radioactive decay, 238U changes through many different isotopes until it finally becomes the stable element of lead (Figure 10).

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

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

---

Example

For example when working in a radiation area for 2 hours at 2 mSv/h (dose rate) the dose is:

\[ 2 \times 2 \times 10^{-3} = 4 \text{ mSv} \]
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 $^{238}$U in the previous section.

<table>
<thead>
<tr>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{226}$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 $^{226}$Ra being converted to $^{222}$Rn (Radon-222) through alpha emission.</td>
</tr>
</tbody>
</table>

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 $^{235}$U and $^{238}$U. The half-life of $^{241}$U is 5 minutes years and the half-life of $^{238}$U is 4,500,000,000 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 11), then its activity can be calculated at another point in time. The equation is:

$$A_t = A_o/2^n$$

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

<table>
<thead>
<tr>
<th>Example</th>
</tr>
</thead>
</table>
| If 37 GBq of $^{32}$P was purchased, how much $^{32}$P would be left one year later? The radiological half-life of $^{32}$P is 14.3 days.  
The number of half-lives of $^{32}$P in 1 year would be:  
365/14.3 which equals 25.5 half-lives  
**Therefore:**  
$n = 25.2, 
A_o = 37$ GBq  
$A_t = 37$ GBq/2$^{25.5}$  
$= 37 \times 10^3 / 47453133$ Bq  
$= 3.7 \times 4.75 \times 10^7$ Bq  
$= 0.778 \times 10^9$ Bq  
$= 778$ Bq |
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 the Radio-toxicity Group assigns a number from 1 to 4 against each isotope. The higher the radio-toxicity group number the more hazardous the isotope.

An adaptation of AS 2243.4 (Standards Association of Australia, 1998) listing the physical properties of commonly used radionuclides in laboratories is provided in Appendix A: Properties of Commonly Used Radionuclides.

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, accidents and detonations around the world.
The relative annual per capita dose in Australia from various sources of radiation is approximately 2.3mSv (Figure 12). ARPANSA (2008) identifies that the largest significant contributing exposure to background radiation is from diagnostic medicine (35%). This is followed by terrestrial sources at 26%.

Figure 12: Annual Australian per capita radiation dose from natural and medical sources (ARPANSA, 2008)

Background ionising radiation levels (from natural radiation sources) in Australia are relatively small in comparison to the other countries (Figure 13). Data from Charles Sturt University (2011) 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 2mSv per annum.

Figure 13: Average annual doses from natural radiation sources (Charles Sturt University, 2011)

4.12 BACKGROUND RADIATION AND DOSE LIMITS

In Section 2.2.4 it was determined that dose limits were regulated by the Radiation Regulations 2007 (Victorian Government, 2007). In Section 3.5 it was also determined that ionising radiation practices at the UoM would be limited to that of a member of the general public (1mSv per annum) and not the occupational dose limits (Table 12) as prescribed by the Radiation Regulations 2007 (Victorian Government, 2007).

When dose limits are assessed they take into account the background radiation. For example the background radiation in Melbourne is approximately 2mSv per annum. This means that UoM personnel working at the Parkville campus would need to receive above 2mSv per annum before it was considered that they had received a radiation dose from their activities.
Table 12: Ionising radiation dose limits

<table>
<thead>
<tr>
<th>Application</th>
<th>Occupational Dose Limit</th>
<th>Public Dose Limit</th>
<th>UoM Dose Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>effective dose(^7)</td>
<td>20 mSv per year, averaged over a period of 5 consecutive calendar years</td>
<td>1 mSv in a year</td>
<td>1 mSv in a year</td>
</tr>
<tr>
<td>lens of the eye</td>
<td>150 mSv</td>
<td>15 mSv</td>
<td>15 mSv</td>
</tr>
<tr>
<td>skin</td>
<td>500 mSv</td>
<td>50 mSv</td>
<td>50 mSv</td>
</tr>
<tr>
<td>hands and feet</td>
<td>500 mSv</td>
<td>50 mSv</td>
<td>50 mSv</td>
</tr>
</tbody>
</table>

\(^7\) Effective dose is defined in Section 4.8.6.

4.13 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ptable (Dayah M, 1997)</td>
<td><a href="http://ptable.com/">http://ptable.com/</a></td>
</tr>
<tr>
<td>The web resource provides an excellent reference to the periodic table. In addition to chemical properties, there is also a function that describes the physical (radiological isotopes) properties of chemical elements.</td>
<td></td>
</tr>
<tr>
<td>A web resource that provides a glossary of radioactive terms</td>
<td></td>
</tr>
</tbody>
</table>

4.14 REFERENCES


HyperPhysics, 2010. Radioactive half-life, Georgia State University, viewed 13 February 2011, [http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/halflf.html](http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/halflf.html).


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 (Princeton University, 2010):

_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 14) may include:
- cell death;
- free radicals;
- chromosomal aberrations;
- mutations; and
- genomic instability.

![Figure 14: Possible cell damage from exposure to radiological material](safety.unimelb.edu.au)

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.

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.

\[8\] Cell image from Baran (2011).
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 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.

### 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). Tuszynski and Dixon (2001) demonstrates this relationship with a number of radioisotopes (Table 13).

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-lives in days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_{\text{Physical}}$</td>
</tr>
<tr>
<td>$^3$H</td>
<td>$4.5 \times 10^4$</td>
</tr>
<tr>
<td>$^{14}$C</td>
<td>$2.1 \times 10^6$</td>
</tr>
<tr>
<td>$^{22}$Na</td>
<td>850</td>
</tr>
<tr>
<td>$^{32}$P</td>
<td>14.3</td>
</tr>
<tr>
<td>$^{35}$S</td>
<td>87.4</td>
</tr>
<tr>
<td>$^{35}$Cl</td>
<td>$1.1 \times 10^5$</td>
</tr>
<tr>
<td>$^{40}$Ca</td>
<td>165</td>
</tr>
<tr>
<td>$^{90}$Fe</td>
<td>45</td>
</tr>
<tr>
<td>$^{90}$Co</td>
<td>$1.93 \times 10^7$</td>
</tr>
<tr>
<td>$^{90}$Zn</td>
<td>244</td>
</tr>
<tr>
<td>$^{87}$Rb</td>
<td>18.8</td>
</tr>
<tr>
<td>$^{87}$Sr</td>
<td>$1.1 \times 10^8$</td>
</tr>
<tr>
<td>$^{99m}$Tc</td>
<td>0.25</td>
</tr>
<tr>
<td>$^{123}$I</td>
<td>0.54</td>
</tr>
<tr>
<td>$^{131}$I</td>
<td>8</td>
</tr>
<tr>
<td>$^{131}$Cs</td>
<td>$1.1 \times 10^8$</td>
</tr>
<tr>
<td>$^{137}$Ba</td>
<td>12.8</td>
</tr>
<tr>
<td>$^{198}$Au</td>
<td>2.7</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>138</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>$5.8 \times 10^8$</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>$2.6 \times 10^9$</td>
</tr>
<tr>
<td>$^{239}$Pu</td>
<td>$8.8 \times 10^9$</td>
</tr>
</tbody>
</table>

Table 13: Radiological and biological half-life (Tuszynski and Dixon, 2001)

**Example**

Consider $^3$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 reduces the exposure.
5.5 **DETERMINISTIC AND STOCHASTIC EFFECTS**

The biological effect of ionising radiation, taking into account the dose, can be divided into two categories:
- deterministic; and
- stochastic.

### 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.

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.

The ICRP has published thresholds [Publication 60 (ICRP, 1991)] for parts of the body in which deterministic effects have been established (Table 14).

<table>
<thead>
<tr>
<th>Body location</th>
<th>Effects</th>
<th>One single absorption (Sv)</th>
<th>Prolong absorption (Sv-year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>testis</td>
<td>permanent infertility</td>
<td>3.5 - 6.0</td>
<td>2</td>
</tr>
<tr>
<td>ovary</td>
<td>permanent infertility</td>
<td>2.5 - 6.0</td>
<td>&gt; 0.2</td>
</tr>
<tr>
<td>lens of eyes</td>
<td>milky lens</td>
<td>0.5 - 2.0</td>
<td>&gt; 0.1</td>
</tr>
<tr>
<td></td>
<td>cataracts</td>
<td>5.0</td>
<td>&gt; 0.15</td>
</tr>
<tr>
<td>bone marrow</td>
<td>blood forming deficiency</td>
<td>0.5</td>
<td>&gt; 0.4</td>
</tr>
</tbody>
</table>

Table 14: Threshold for deterministic effects (Sv) to parts of the body (ICRP, 1991)

**Cataracts**

Cataracts can be induced when a single dose exceeding approximately 2 to 3 Sv is delivered to the lens of the eye. In lower doses radiation-induced cataracts may take many months or years to appear (Table 14).

### 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.
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.

#### 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 particular organ(s) with a slower rate of elimination.

Internal control measures will differ from external control measures. These are detailed in Section 6.3.
When different elements are taken into the body they will accumulate in specific organs and/or tissues. These are referred to as target organs or tissues.

Examples include iodine, cesium and plutonium (Figure 15) where:
- iodine accumulates in the thyroid;
- cesium accumulates in the muscle and soft tissue; and
- plutonium accumulates in the lung, liver and bone.

Consider iodine-131 ($^{131}$I). When iodine is ingested it will accumulate in the thyroid. Therefore when $^{131}$I is ingested the main biological effects/changes due to ionising radiation will also occur in the thyroid.

### 5.7 PUTTING RISK INTO PERSPECTIVE

The following discussion puts into perspective the risks associated with ionising radiation. In particular it highlights that under normal circumstances, including undertaking activities that use ionising radiation, the risk of exposure and adverse effects is very low.

In the first discussion 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. Causes of death can be allocated an estimate of LLE (Table 15).

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

Table 15: Examples of loss of life expectancy (Cohen, 2002)
In the second discussion consider the radiological risk by comparing differing doses of external radiation exposure (Table 16). In particular compare the outcomes of the public dose limits of 1 mSv to significantly higher doses of whole body exposure.

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

Table 16: Effects of whole body exposure from differing doses of external radiation

Aside from natural background radiation the medical field is a major source of radiation exposure. The majority of this exposure is from diagnostic imaging, such as x-rays and computed tomography scans. Cohen9 (1991) provides a snap shot of the typical exposures that can be expected through various radiological diagnostic procedures (Table 17).

<table>
<thead>
<tr>
<th>Radiological Procedure</th>
<th>Effective dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computed Tomography (CT)-Abdomen</td>
<td>10 mSv</td>
</tr>
<tr>
<td>Computed Tomography (CT)-Body</td>
<td>10 mSv</td>
</tr>
<tr>
<td>Intravenous Pyelogram (IVP)</td>
<td>1.6 mSv</td>
</tr>
<tr>
<td>Radiography-Lower GI Tract</td>
<td>4 mSv</td>
</tr>
<tr>
<td>Radiography-Upper GI Tract</td>
<td>2 mSv</td>
</tr>
<tr>
<td>Computed Tomography (CT)-Head</td>
<td>2 mSv</td>
</tr>
<tr>
<td>Radiography-Chest</td>
<td>0.1 mSv</td>
</tr>
<tr>
<td>Computed Tomography (CT)-Chest</td>
<td>8 mSv</td>
</tr>
<tr>
<td>Voiding Cystourethrogram</td>
<td>5-10 yr. old: 1.6 mSv</td>
</tr>
<tr>
<td>Infant: 0.8 mSv</td>
<td></td>
</tr>
<tr>
<td>Mammography</td>
<td>0.7 mSv</td>
</tr>
</tbody>
</table>

Table 17: Radiological procedures and their effective doses (Cohen, 1991)

9 Whilst these figures are approximately twenty years old they are still comparative with recent data.
5.8 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are ionising radiation fact sheets available from the ARPANSA web site</td>
<td></td>
</tr>
</tbody>
</table>

5.9 REFERENCES


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 (ICRP, 2007) the three principles have remained.

To summarise the three principles of radiological protection are:
- justification of radiological exposure;
- optimisation of protection; and
- individual dose limitation.

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 as a result 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. In particular 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 laboratory process at the University exposes a staff to 1.5 mSv per year. To reduce the exposure through engineering controls by 0.5 mSv may cost the department 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.

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 UoM is 1 mSv per year. Therefore the principle of limitation requires that all activities at the UoM will not expose personnel to >1 mSv per year.

6.1.4 Controls Determined by Routes of Exposure

Not only the physical properties of an ionising source be considered when planning controls to limit/minimise exposure but also the route (or possible route) of radiological exposure should be taken into account. In Section 5.6 radiological exposures routes were divided into external or internal types.

Therefore planning controls to limit radiological dose should take into account both external and internal exposure.

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 lows as reasonably achievable, social and economic factors being taken into account.
6.2 CONTROLS TO PREVENT EXTERNAL EXPOSURE

The three primary means for eliminating or reducing external radiological exposure are:
- time;
- distance; and
- shielding.

6.2.1 Time

The dose accumulated by a person working in an area with a particular dose rate 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 can be expressed by the following equation:

\[ \text{Dose} = \text{dose rate} \times \text{time} \]

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

Example

The annual dose rate for staff at the UoM 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 µSv/week = 10 µSv/hour \times \text{time}

Time = 2 hours per week

6.2.2 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 16). This is known as the inverse square law and can be calculated from the following equation:

\[ \text{Dose rate} = \frac{1}{\text{distance}^2} \]

This can also be written as:

\[ D_1 r_1^2 = D_2 r_2^2 \]

\[ D = \text{dose rate} \quad r = \text{distance (radius)} \]

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.

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.
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 µSv/h. Each radionuclide will have a respective gamma ray constant. The gamma ray constants for commonly used radionuclides are detailed in Appendix A.

The equation for calculating the dose rate for gamma sources is:

\[
\text{Dose rate} = \frac{\Gamma A}{r^2}
\]

\(\Gamma\) = gamma ray constant in µSv/h
\(A\) = activity in GBq
\(r\) = distance in metres (radius)

### 6.2.3 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.

Shields are important for radiation sources that emit x-rays, gamma rays, beta particles or neutrons.

#### 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.
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

One 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 amount of x-rays being emitted.

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.

Perspex can be used to shield beta particles.

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

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

Z number

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

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.

Half-Value Layer

The half-value layer (HVL) of a shield quantifies the thickness 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 can be calculated from the following equation:

\[ I = I_o/2^n \]

\( I = \) shielded dose rate \( I_o = \) 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 can be calculated from the following equation:

\[ I = I_0 / 10^n \]

\( I = \) shielded dose rate \hspace{1em} \( I_0 = \) unshielded dose rate \hspace{1em} \( n = \) number of tenth-value layers

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

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

Table 18: HVL and TVL shielding requirements gamma rays (Jones, 2003)

Summary of Shielding

Table 19 provides a summary of radiation properties and their relationship to shielding requirements.

<table>
<thead>
<tr>
<th>Type of Radiation</th>
<th>Symbol</th>
<th>Electrical Charge</th>
<th>Penetration</th>
<th>Ionising Strength</th>
<th>Shield Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>alpha (helium nuclei)</td>
<td>α</td>
<td>+ + charge</td>
<td>short</td>
<td>strong</td>
<td>paper, skin</td>
</tr>
<tr>
<td>beta (electrons)</td>
<td>β</td>
<td>− charge</td>
<td>moderate</td>
<td>moderate</td>
<td>aluminium, perspex</td>
</tr>
<tr>
<td>neutron (neutrons)</td>
<td>n</td>
<td>no charge</td>
<td>short to high</td>
<td>weak to strong</td>
<td>hydrogen rich eg. paraffin, water</td>
</tr>
<tr>
<td>Gamma</td>
<td>γ</td>
<td>no charge</td>
<td>high</td>
<td>weak</td>
<td>lead, concrete</td>
</tr>
<tr>
<td>X-ray</td>
<td>X</td>
<td>no charge</td>
<td>high</td>
<td>weak</td>
<td>lead, concrete</td>
</tr>
</tbody>
</table>

Table 19: Summary of radiation properties and shielding requirements
6.3 CONTROLS TO PREVENT INTERNAL EXPOSURE

The principles of internal protection/contamination control (Figure 17) are:

1. Contain:
   - limit the area where sources are used – provide a designated space for radiation activities in the laboratory
   - restrict access to the where the sources are used – keep a list of authorised users and ensure that unauthorised personnel cannot access the radiation sources
   - provide adequate ventilation – fume hoods
   - use personal protective equipment – gloves, laboratory coats, glasses

2. Clean:
   - employ a high standard of housekeeping techniques
   - determine laboratory rules that include, no smoking, eating or drinking

3. Minimise:
   - use the smallest activity of radiation source that is suitable for the task

Staff training is also essential and is discussed in Section 11.1. This includes:
- local induction for new personnel; and
- ionising radiation safety training.

Radioactive contamination

Radioactive contamination is a radiation source in any location where it is not intended, and predominantly where its incidence may be harmful or result in a radiation hazard.

Figure 17: Controls to prevent internal exposure
6.4 EFFECTIVE CONTROL

6.4.1 Case Study

Background

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

Activity

The $^{60}$Co source was contained in a large shielded vessel. In order to remove the source from the University and transport it to another location a number of steps were involved. These included:

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

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

Lifting the containment vessel.

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

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

Radiation Dose

The technicians from ANSTO received a radiation dose of 14 µSv from this activity. In comparison whilst flying from Sydney to Melbourne they had received 7 µSv.

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 $^{60}$Co and the subsequent risks
- skill and experience – the technicians had extensive skills and experience working both with $^{60}$Co and other radiological materials with a high activity
- work practices – the technicians applied adhered to standard operating procedures developed specifically for the activity.
6.4.2 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 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are useful ionising radiation fact sheets available from the ARPANS web site</td>
<td></td>
</tr>
</tbody>
</table>

Australian Standards (administered through SAI Global).
The UoM has a subscription to the Standards. They can be accessed through the UoM library Discovery search.

A UoM user name and password is required.

Instructions:

1. Log-on to the UoM library Discovery search from the library home page. Link: [http://www.library.unimelb.edu.au/](http://www.library.unimelb.edu.au/)
2. Select “Find Database” and access the Standards through SAI

6.6 REFERENCES

HyperPhysics, 2010. *Inverse square law, general*, Georgia State University, viewed 15 February 2011, [http://hyperphysics.phy-astr.gsu.edu/hbase/forces/isq.html](http://hyperphysics.phy-astr.gsu.edu/hbase/forces/isq.html).


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

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 exiting 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).

Figure 19: Supplementary ionising radiation symbol (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 2007 (Victorian Government, 2007) mandate specific requirements for hazardous chemicals.
The UoM Chemical management guidelines provide instruction on these requirements.

A chemical within a container must be identified by a label that is written in English and it should include:

- the product name of the chemical;
- the name, address and contact telephone number of the Australian manufacturer or importer of the substance;
- the chemical name for all Type I ingredients
- the chemical name (or generic name if it is commercially confidential) for Type II ingredients;
- relevant health and safety information about the substance, including its risk and safety phrases, except where the container is so small that it is not practical to provide such information; and
- other information relevant to the chemical classification (for example, hazardous substances require the word the word “HAZARDOUS” clearly and prominently displayed).

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 or the chemical has a long name) 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 personnel 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 also take into account 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 (Victorian Government, 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 Legal Requirements.

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 Signage – OHS Requirements Procedure.

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 personnel 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 20).

<table>
<thead>
<tr>
<th>Radiation Source</th>
<th>Examples of Storage/Security Arrangements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low level open sources</td>
<td>Locked refrigerator/cupboard (whichever is applicable)</td>
</tr>
<tr>
<td></td>
<td>Restricted access to area</td>
</tr>
<tr>
<td>X-ray machine</td>
<td>X-ray is locked out when not in use – with a key</td>
</tr>
<tr>
<td></td>
<td>Restricted access to area</td>
</tr>
<tr>
<td>Neutron probe</td>
<td>Locked store room – restricted access to storeroom</td>
</tr>
</tbody>
</table>

Table 20: Examples of storage arrangements for radiation sources
There may additional security requirements for the storage of some radiation sources. These requirements are outlined in the *Code of practice security of radioactive sources* (ARPANSA, 2007) (Figure 20).

The Code identifies a number of radioactive sources (sealed sources) that are deemed to be “security enhanced”. These radioactive sources are named in the Code.

Generally speaking at the UoM local areas and departments are not affected by this Code.

![Figure 20: Code of practice security of radioactive sources (ARPANSA, 2007)](image)

### 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 particular 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 particular 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 the material safety data sheet (MSDS\(^\text{10}\)).

Further requirements and guidance on chemical management are outlined in:

- the *Chemical Risk Management Procedure*; and
- the *Chemical Management Guidelines*.

---

\(^\text{10}\) The UoM *Chemical Management Guidelines* contain additional information on MSDS requirements.
7.3 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>UoM Chemical Management web page contains</td>
<td></td>
</tr>
<tr>
<td>information on:</td>
<td></td>
</tr>
<tr>
<td>• General Guidance</td>
<td></td>
</tr>
<tr>
<td>• Material Safety Data Sheets</td>
<td></td>
</tr>
<tr>
<td>• Chemical Inventories</td>
<td></td>
</tr>
<tr>
<td>• Chemical Risk Assessment</td>
<td></td>
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<tr>
<td>• Storage and Handling</td>
<td></td>
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<tr>
<td>• Poisons Control Plan</td>
<td></td>
</tr>
<tr>
<td>• Government and External Party Publications</td>
<td></td>
</tr>
<tr>
<td>• Chemical Risk Management Procedure</td>
<td></td>
</tr>
<tr>
<td>• Signage – OHS Requirements Procedure</td>
<td></td>
</tr>
</tbody>
</table>

7.4 REFERENCES


8 MONITORING EQUIPMENT

8.1 RADIATION MONITORS

The UoM Radiation Management Plan requires that individuals working with radiation sources wear personal monitoring devices (where applicable) to record the level of radiation they are exposed to while performing their work. Thermoluminescent dosimetry (TLD) monitors are used for this purpose.

8.1.1 Thermoluminescent Dosimetry Monitor

A thermoluminescent dosimetry (TLD) monitor contains a wafer of energy sensitive plastic (CR-39) housed in a paper wrap. This is normally mounted in a familiar red or blue badge holder. The badges contain filters that block different types and energies of radiation. These filters can therefore be used to determine the type and the energy of radiation that the monitor is exposed to.

The red badge houses a TLD monitor designed to detect medium energy beta particles and gamma/x-rays. The blue badge houses a TLD monitor designed to detect neutrons and gamma/x-rays.

Personal TLD monitors are compared with the annual allowable dose limits to provide an individual picture of radiation exposure over a period of time.

TLD monitors are intended to minimise both deterministic and stochastic effects.

<table>
<thead>
<tr>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLD monitors cannot detect alpha particles or low energy beta particles.</td>
</tr>
</tbody>
</table>

Figure 21: Examples of TLD monitors

Thermoluminescent Dosimetry Badge

TLD monitors (Figure 21) are used extensively at the UoM. It is expected that personnel working with radiation sources are issued with a personal TLD monitor. A TLD monitor is used only by the person that it is issued to and cannot be shared. If a TLD monitor is lost or damaged it should be reported to the supervisor as soon as possible.

TLD Monitor Requirements

The routine procedure for TLD 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.

A TLD monitor can also provide a method of monitoring work practices. For example if a particular number of people undertaking the same activity in the same area show an elevated dose this may indicate a problem with the controls. Controls in place for that activity would therefore be reassessed.

The disadvantage of a TLD monitor is the delay in receiving the results. As the TLD 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 at all times.
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 TLD 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 for a number of personnel; and
- the monitors have pre-set alarm levels.

Currently the UoM Radiation Safety Adviser holds a limited number of real time neutron/gamma monitors and beta/gamma monitors (Figure 22) that can be issued to staff for specific needs. The monitor on left in Figure 22 measures neutron/gamma radiation and the monitor on the right measures beta/gamma radiation.

![Figure 22: Examples of real time dose monitors](image)

8.2 METERS

Radiation meters fall into two main groups (Figure 23):
- survey meters; and
- contamination meters.

![Figure 23: Examples of survey and contamination meters](image)

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 (μSv) 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 personal ionising radiation exposure.

8.2.2 Contamination meters

Contamination meters measure external radiation in units of counts per second (cps) or Bq/cm². 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.
8.2.3 Considerations

When using a radiation meter it is important to understand the functions and the limitations of the meter. 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 undertake a survey of a biological risk\(^ {11} \)); and
- the level of efficiency when measuring radiation (see Table 21).

Meters are not 100% accurate at measuring ionising radiation. For example Table 21 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.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Emax2(\pi) (keV)</th>
<th>2(\pi) Effic %</th>
<th>Sensitivity cps/Bq/cm(^2)</th>
<th>MDL Bq/cm(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{14})C</td>
<td>156</td>
<td>3</td>
<td>0.25</td>
<td>9.0</td>
</tr>
<tr>
<td>(^{35})S</td>
<td>167</td>
<td>8</td>
<td>0.65</td>
<td>3.7</td>
</tr>
<tr>
<td>(^{147})Pm</td>
<td>224</td>
<td>15</td>
<td>1.25</td>
<td>2.0</td>
</tr>
<tr>
<td>(^{99})Tc</td>
<td>290</td>
<td>20</td>
<td>1.75</td>
<td>1.5</td>
</tr>
<tr>
<td>(^{90})Sr + (^{90})Y</td>
<td>580 + 2280</td>
<td>50</td>
<td>8.50</td>
<td>0.3</td>
</tr>
<tr>
<td>(^{36})Cl</td>
<td>714</td>
<td>45</td>
<td>3.50</td>
<td>0.7</td>
</tr>
<tr>
<td>(^{210})Pb</td>
<td>1160</td>
<td>50</td>
<td>4.00</td>
<td>0.6</td>
</tr>
<tr>
<td>(^{32})P</td>
<td>1710</td>
<td>70</td>
<td>5.50</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 21: Performance (surface sensitivity – in contact) beta emitting isotopes

8.2.4 Purchasing Meters

When purchasing a meter operational considerations should be taken into account (Table 22). Operational considerations refer to not only the intended use of the meter but also the meter’s functionality.

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

Table 22: Operational considerations when purchasing a radiation meter

\(^{11}\) Biological risk is where we measure the radiological risk to ourselves
8.2.5 Operational and Calibration Requirements

The general operational and calibration requirements for most survey meters are similar with only minor differences (Table 23).

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

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Survey Meter</th>
<th>Contamination Meter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General inspection</strong></td>
<td>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 appeared damaged?</td>
<td>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 appeared 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.</td>
</tr>
<tr>
<td><strong>Calibration</strong></td>
<td>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.</td>
<td>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 measuring dose rate.</td>
</tr>
<tr>
<td><strong>Operational Check</strong></td>
<td>A survey meter should be regularly assessed (weekly) to ensure that it continues to monitor consistently over time.</td>
<td>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.</td>
</tr>
<tr>
<td><strong>Battery</strong></td>
<td>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.</td>
<td>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.</td>
</tr>
<tr>
<td><strong>Response</strong></td>
<td>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.</td>
<td>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.</td>
</tr>
</tbody>
</table>

Table 23: Operational and calibration requirements of survey and contamination meters

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.
8.2.6 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 radioactive source with a known activity at a predetermined distance from the contamination meter. Measure the activity of the source (Figure 24).

2. At regular scheduled intervals (e.g. weekly) repeat the above measurements. Ensure that the radioactive source has the same activity and is placed at the same distance from the contamination meter.

3. Compare the measurement results over a period of time (Figure 25). The results should be fairly 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 25 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 24: Placement of a radioactive source with a known activity at a predetermined distance](image)

![Figure 25: Contamination meter chart showing meter results over a period of time](image)
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 (Standards Association of Australia, 1998).

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.

8.3.3 Airborne Contamination Survey

Airborne contamination surveys are undertaken in areas where activities may produce airborne radioactive contamination or as a means 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 activity and the radiation source been monitored (Table 24).

Some radiation surveys may be a legal requirement. For example a requirement of the UoM radiation Management Licence includes annual wipe testing soil moisture/density gauges\(^\text{12}\). Use Licence holders also have an obligation to conduct radiation surveys before and after the use of an unsealed source.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Type of Radiation Survey</th>
<th>Frequency</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emitting apparatus – x-ray</td>
<td>External</td>
<td>During and immediately after installation</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quarterly</td>
<td>The survey ensures ongoing expected patterns of radiation. Changes in patterns of radiation or elevated levels can indicate damage or compromise to the equipment.</td>
</tr>
<tr>
<td>Sealed source – soil moisture/density gauge</td>
<td>Surface Contamination</td>
<td>Annually</td>
<td>The survey ensures that the housing around the sealed source is intact and that radioactive contaminants are not leaking.</td>
</tr>
<tr>
<td>Open source</td>
<td>Surface Contamination</td>
<td>Completion of activity</td>
<td>The survey ensures that on completion of an activity a radiation source is not carried into other areas beyond the designated radiation area.</td>
</tr>
</tbody>
</table>
| Radiation store           | External survey and Surface Contamination | Annually                | The surveys ensure:  
• the continued low level of expected radiation; and  
• radioactive contaminants remain intact and are not carried outside the store. |

Table 24: Common radiation survey requirements for the UoM

### 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.

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\(^{12}\) The requirement to wipe test soil moisture/density gauges is outlined in the *Code of practice and safety guide for portable density/moisture gauges containing radioactive sources* 2004, Radiation Protection Series Publication No. 5 (ARPANSA, 2004).
8.5 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Services, Occupational Health and Safety radiation advice email address</td>
<td><a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a></td>
</tr>
<tr>
<td>Departmental Radiation Safety Officer contacts list</td>
<td><a href="http://safety.unimelb.edu.au/topics/radiation/drso/">http://safety.unimelb.edu.au/topics/radiation/drso/</a></td>
</tr>
<tr>
<td>Australian Standards (administered through SAI Global). The UoM has a subscription to the Standards. They can be accessed through the University Library Discovery search.</td>
<td>Instructions: 1. Log-on to the UoM library Discovery search from the library home page. Link: <a href="http://www.library.unimelb.edu.au/">http://www.library.unimelb.edu.au/</a>  2. Select “Find Database” and access the Standards through SAI</td>
</tr>
<tr>
<td>A UoM user name and password is required.</td>
<td></td>
</tr>
</tbody>
</table>

8.6 REFERENCES


9 INCIDENTS AND EMERGENCIES

9.1 MANDATORY REPORTING OF RADIOPHYSICAL INCIDENTS

All holders of a radiation Management Licence, as a condition of the licence, must report “radiation incidents” to the Department of Health. The Mandatory reporting of radiation incidents (Department of Health, 2012) prescribe these incidents based on the use of the radioactive 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 into account the requirements for reporting radiophysical incidents. Therefore the DRSO should be contacted following any radiation incident to determine if there are mandatory reporting requirements.

The DRSO shall contact the UoM Radiation Safety Adviser for clarification and/or assistance following a radiophysical incident. The UoM shall notify the Department of Health in the prescribed manner where a radiophysical incident must be reported.

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 can 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, UoM emergency phone);
- make the area safe (if safe to do so);
- evacuate personal 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 UoM Radiation Safety Adviser for assistance and advice. The UoM Radiation Safety Adviser shall notify the Department of Health (as discussed in Section 9.1) of radiological incidents that must be reported.

The OHS, Incident, Injury and Hazard Reporting And Investigation Procedure should be followed. This includes:

- entering the incident/emergency into Themis; 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 personnel 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).

As part of the local area induction, all personnel 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.
### 9.5 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Melbourne procedure:</td>
<td></td>
</tr>
<tr>
<td>University of Melbourne procedure:</td>
<td></td>
</tr>
<tr>
<td>University of Melbourne procedure:</td>
<td></td>
</tr>
<tr>
<td>The UoM First Aid web page provides first aid information, resources and links to:</td>
<td></td>
</tr>
<tr>
<td>• Basic First Aid Kit Contents</td>
<td></td>
</tr>
<tr>
<td>• First Aid – OHS Requirements Procedure</td>
<td></td>
</tr>
<tr>
<td>• First aid training advice</td>
<td></td>
</tr>
<tr>
<td>• First aid risk assessment templates for a number of workplace scenarios</td>
<td></td>
</tr>
<tr>
<td>Common Services, Occupational Health and Safety radiation advice email address</td>
<td><a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a></td>
</tr>
</tbody>
</table>

### 9.6 REFERENCES

10 RADIOACTIVE WASTE MANAGEMENT

10.1 INTRODUCTION

When disposing of radioactive sources all personnel, must comply with the:

- Disposal of radioactive materials (Department of Health, 2011a); and
- UoM disposal of radioactive sources

10.2 METHODS OF RADIOACTIVE WASTE MANAGEMENT

Radioactive waste normally refers to radioactive materials, in particular:

- 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 above radioactive sources are commonly listed in schedules 3, 4 and 5 of the UoM radiation Management Licence.

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.

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. They 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 then disposed of in non-radioactive waste. This waste can then be disposed of through the appropriate waste stream.

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 Common Services, Occupational Health and Safety.

10.3 UNIVERSITY REQUIREMENTS

The UoM uses the categories described in Section 10.2 when disposing of radioactive wastes (open sources). Table 25 provides some examples of various radioactive open sources and the means by which they are disposed of at the UoM.

Local areas must have waste management procedures for the radioactive waste they generate. General waste management requirements are outlined in the Waste Risk Management Procedure.

Where personnel are unsure of the appropriate waste strategy they should contact the DRSO for advice.
Advice may also be sought by contacting Common Services, Occupational Health and Safety via the hazardous waste email or the radiation advice email.

<table>
<thead>
<tr>
<th>Disposal Method</th>
<th>Examples</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilution and dispersion</td>
<td>14C</td>
<td>UoM Hazardous Waste Collection A specialist contractor licensed by the Environmental Protection Agency (EPA). These collections are managed by Common Services, Occupational Health and Safety.</td>
</tr>
<tr>
<td></td>
<td>3H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3H</td>
<td></td>
</tr>
<tr>
<td>Delay and decay</td>
<td>32P and 33P</td>
<td>UoM Hazardous Waste Collection A Specialist contractor licensed by the EPA. These collections are managed by Common Services, Occupational Health and Safety.</td>
</tr>
<tr>
<td></td>
<td>32P and 33P</td>
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<td></td>
<td>32P and 33P</td>
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</tr>
<tr>
<td>Concentration and</td>
<td>137Cs</td>
<td>Arrangements by Common Services, Occupational Health and Safety Common Services, Occupational Health and Safety can be contacted to determine appropriate waste management of these.</td>
</tr>
<tr>
<td>containment</td>
<td>137Cs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>137Cs</td>
<td></td>
</tr>
</tbody>
</table>

Table 25: Disposal methods of radioactive waste management at the UoM

10.3.1 UoM Hazardous Waste Collection

Radioactive waste can be included in the UoM 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 Amendment Act 2013 (Victorian Government, 2013).

Preparing radioactive waste for collection requires suitable packaging and labelling. The radioactive 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.

If the waste is below the legislative prescribed activity concentration, then 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 a number of ways. For example by:

- emailing Common Services, Occupational Health and Safety waste collection email address (48 hours prior to the scheduled collection);
- contacting the DRSO; or
- contacting the department manager.

<table>
<thead>
<tr>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove all radioactive markings, symbols and markings before placing the waste out for collection.</td>
</tr>
<tr>
<td>Label the waste so that it is clearly identifiable (eg chemical).</td>
</tr>
<tr>
<td>Select a suitable container that will hold the waste.</td>
</tr>
</tbody>
</table>
10.3.2 Containment of Waste

Radioactive wastes that require concentration and containment are managed by Common Services, Occupational Health and Safety.

Local areas should contact their DRSO who will assess the radiological waste and prepare for local storage. Where required the DRSO will contact the UoM Radiation Safety Adviser who will make arrangements for the removal of the radioactive waste.

10.4 DISPOSAL

Radiation apparatus and sealed source apparatus for disposal may require different disposal pathways from those previously discussed. The UoM Radiation Safety Adviser must be contacted where a radiation source or sealed source apparatus requires disposal. The appropriate disposal method shall be determined on a case by case basis.

It is important to note that when a radiation source or sealed source apparatus is disposed of then:

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

The UoM Radiation Safety Adviser shall provide the Department of Health with details of the disposed radiation apparatus or sealed source apparatus.

<table>
<thead>
<tr>
<th>Disposal of X-ray Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray equipment must be rendered inoperable before disposal. The method of decommissioning will be determined by the type of x-ray equipment.</td>
</tr>
<tr>
<td>Older x-ray equipment may contain hazardous materials such as polychlorinated biphenyl (PCB) (Department of Health, 2011b). Therefore it is important to contact the UoM Radiation Safety Adviser.</td>
</tr>
</tbody>
</table>

10.5 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Melbourne procedure:</td>
<td><a href="http://safety.unimelb.edu.au/publications/procedure/chemical/">Chemical Risk Management Procedure</a></td>
</tr>
<tr>
<td>Common Services, Occupational Health and Safety radiation advice email</td>
<td><a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a></td>
</tr>
<tr>
<td>Common Services, Occupational Health and Safety hazardous waste advice and collection email address</td>
<td><a href="mailto:hazardouswaste-info@unimelb.edu.au">hazardouswaste-info@unimelb.edu.au</a></td>
</tr>
<tr>
<td>The UoM Chemical Management Guidelines also outlines the requirements for the disposal of chemical wastes. It may also be applicable to the management of radioactive wastes, particularly:</td>
<td><a href="http://safety.unimelb.edu.au/docs/Chemical_Management_Guidelines.pdf">http://safety.unimelb.edu.au/docs/Chemical_Management_Guidelines.pdf</a></td>
</tr>
<tr>
<td>• dilution and dispersion; and</td>
<td></td>
</tr>
<tr>
<td>• delay and decay.</td>
<td></td>
</tr>
</tbody>
</table>
10.6 REFERENCES


11 SUPERVISOR/MANAGER RESPONSIBILITIES

11.1 INDUCTION AND TRAINING

The supervisor/manager has a responsibility for ensuring that personnel 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 personnel 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 personnel with information regarding the local area such as:
- facilities:
- safety requirements and systems;
- safety personnel: and
- emergency procedures.

All personnel 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 TLD 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

Personnel who work with radiation sources require ionising radiation training prior to commencing work.

After identifying the ionising radiation training needs of personnel under their supervision, the supervisor/manager should ensure that this information is included on the local area training matrix.

After personnel have completed ionising radiation training the supervisor/manager should ensure that a record of this training is kept. In relation to UoM personnel, ionising radiation training is entered into Themis by Common Services, Occupational Health and Safety. In relation to non-University personnel (who are not on Themis) records are maintained by the department/local area.

UoM Training Package

Ionising radiation training packages are developed, maintained and delivered by Common Services, Occupational Health and Safety. The purpose of the training is to provide information on ionising radiation theory and requirements. The emphasis is on working safely with ionising radiation taking into account relevant UoM policy and procedures.
The ionising radiation packages include:
- Safe Radiation Practices – Ionising
- Safe Radiation Practices – Neutron Probe
- Safe Radiation Practices – Ionising (DEXA)
- Safe Radiation Practices – (Departmental Radiation Safety Officers)
- Safe Radiation Practices – (Iodine 131)

Safe Radiation Practices – Ionising training is required for all personnel working with radiation sources. There are eleven elements with associated performance criteria for Safe Radiation Practices – Ionising. The training takes approximately 1½ hours. This includes a small assessment at the end of the session.

Participants who attend the Safe Radiation Practices – Ionising training and successfully complete the assessment can request a certificate of attainment (Figure 27) from Common Services, Occupational Health and Safety.

Training can be arranged on-line through Themis. Additional training sessions can be arranged by contacting the DRSO or contacting Common Services, Occupational Health and Safety.

General training requirements are outlined in the OHS Training Procedure.

Figure 27: Certificate of attainment

11.2 RISK ASSESSMENT

Risk assessment is the process of:
- determining the hazards to health and safety that exist for a particular task, 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 a minimum identified hazards, assessed risks and controls associated with radiation sources should take into account:
- the type, energy and activity of the ionising radiation;
- the dose rate; and
- the route of exposure.

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.

Risk assessment requirements are outlined in the OHS Risk Management Procedure.

The UoM uses two variable or three variable risk assessment methodologies when assigning risk ratings to identified hazards. Risk assessment templates have been developed for radiation sources (Table 26).
### Incidents and Emergencies

It is important that risk assessments take into account possible radiological incidents and emergencies.

### 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). Listed below in order of effectiveness.

**a. Elimination:**
- Remove the radiation hazard. Eg eliminating a requirement to use a radiation source..

**b. Substitution:**
- Replace the radiation source with a less hazardous form. eg. replacing an open source with a shorter half-life, less energy and lower biological impact.

**c. Engineering Controls:**
- Engineering the solution to minimise risk the 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.

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

**e. Personal Protective Equipment (PPE):**
- PPE is the last and least effective control method used. For example it may involve staff and students wearing appropriate gloves and laboratory coats whilst working with open isotopes. It may also require wearing sturdy enclosed shoes whilst working with a moisture gauge. Here the PPE is to provide protection against accidental dropping of the moisture gauge. It has nothing to do with the neutron source.

**Note:** Also refer to the controls to prevent external exposure and internal exposure (Section 6.2 and Section 6.3) 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 take into account the identified risks and the required controls outlined in the risk assessment.

The *OHS Risk Management Procedure* outlines the following requirements when developing an SOP:
- Personnel in consultation with supervisors/managers, shall develop SOPs or OHS work instructions for specific tasks or operations.
- Supervisor/managers shall ensure SOPs or OHS work instructions contain suitable document control.
- Supervisor/managers can use the University SOP template for SOPs or OHS work instructions.

11.4 **PURCHASING**

11.4.1 **New Radiation Sources**

When a local area intends to acquire a new radiation source there will be additional requirements that are not included in the pre-existing arrangements. These are:
- completing a Health and Safety Pre-Purchase Checklist; and
- notifying the DRSO and the UoM Radiation Safety Adviser to confirm:
  - the local area is able to possess the radiation source (eg is already on the Management Licence); or
  - the user does or does not require a Use Licence.

11.4.2 **Completing a Health and Safety Pre-Purchase Checklist**

A health and safety pre-purchase risk assessment addresses a number of considerations prior to purchasing new radiation sources including:
- the likelihood of new or additional hazards as a result 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 *Purchasing – OHS Requirements Procedure*. 
11.4.3 Notifying the DRSO and the UoM Radiation Safety Adviser

Notifying the DRSO and the UoM Radiation Safety Adviser ensures that the new radiation source is included on the UoM radiation Management Licence. It also ensures that the local area is provided with the conditions of the UoM radiation Management Licence under which that radiation source can be used.

Prior to purchase the local area DRSO must be notified so that they can:
• add the radiological material to the local area inventory;
• provide guidance where required; and
• notify and seek advice from the UoM Radiation Safety Adviser.

Prior to purchase the UoM Radiation Safety Adviser must be notified so that they can:
• add the radiation source to the UoM Radiation Management Licence (refer to Section 2.2.4); and
• provide guidance where required.

The UoM Radiation Safety Adviser arranges the documentation and notification to the Department of Health for new radiation sources. The documentation may vary depending on the radiation source being acquired.

Radiation Apparatus or Sealed Source Apparatus

When a local area intends to acquire a radiation apparatus or sealed source apparatus that is not on the UoM radiation Management Licence the Department of Health require the following documentation:
• a Notice of Acquisition; and
• an Application to Vary a Management Licence.

Radioactive Material

When a local area intends to acquire radioactive material that is not on the UoM radiation Management Licence the Department of Health require the following application:
• an Application to Vary a Management Licence.

11.4.4 Ongoing Radiation Sources

Local areas have pre-existing arrangements in place to enable the ongoing purchase of radiation sources that are already listed on the UoM Radiation Management Licence. These arrangements may include:
• contacting the DRSO to arrange purchase;
• contacting the UoM Radiation Safety Adviser 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. It can be appreciated that legal requirements around transportation of radiation sources is both highly regulated and complex.

Given the complex regulatory requirements, it is not expected that managers/supervisors are familiar with transportation requirements. However it is expected that managers/supervisors will seek advice where transportation of radiation sources is required.

The purpose of this section is to ensure managers/supervisors appreciate the transport requirements associated with radiation sources.

The objective of legislation is to ensure that neither the transporters nor members of the public are exposed to unacceptable exposure to radiation during transport. In addition transport requirements take into account the “what if scenario”. In the case of an incident the risk of exposure is mitigated or minimised.
With regards to transport particular attention should be paid to:

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

### UoM Radiation Management Licence and Transport Requirements

The conditions of use on UoM Radiation Management Licence include that Schedule 3 radiological materials (soil moisture/density gauges) comply with the *Code of practice and safety guide for portable density/moisture gauges containing radioactive sources 2004* (ARPANSA, 2004). Therefore the requirements of the *Code of practice for the safe transport of radioactive material 2008* (ARPANSA, 2008a) must also be met. Refer to (Table 3).

UoM management plans have been developed to ensure that transportation of these gauges meets the above the requirements of the above codes.

#### 11.5.1 Legal Requirements

**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* (Australian Government, 2007) 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.

**Labelling**

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 28).

Each label represents the potential ionising radiological hazard of the package.

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.
Placarding

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

The Dangerous Goods (Storage and Transport) Regulations 2012 (Victorian Government, 2012) categorises a radiation source as a Class 7 Dangerous Good. The Australian Code for the Transport of Dangerous Goods by Road & Rail (Australian Government, 2007) determines the symbol, size and layout of a Class 7 placard (Figure 29). The Code is referred to as the Australian Dangerous Goods (ADG) Code.

The ADG Code determines the placard location on a vehicle during the transport of a Class 7 Dangerous Good. For example when transporting a soil moisture/density gauge three placards must be displayed on the vehicle; one on each side, and one on the back.

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 µSv/h.

Importantly this reduces the transport requirements associated with radiation sources. For example exempt 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 indicates the presence of a radiation source without the tri-foil symbol (Figure 30). Compare these labelling requirements with the labelling requirements of radiation sources that are not exempt (Figure 28).
11.5.2 University Requirements

It is not expected that supervisors/managers will have a clear understanding of the transport requirements associated with radiation sources. However there are severe penalties for individuals who fail to comply with regulatory requirements. Therefore supervisors/managers should contact the UoM Radiation Safety Adviser for assistance.

Packaging

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 can be used. The package should be sealed and the appropriate label affixed.

A Consignor's Declaration for Dangerous Goods should be completed (ARPANSA, 2009).

Emergency Procedures

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

- spill kit;
- instructions on emergency response; and
- emergency contact numbers.
### 11.6 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Melbourne procedure:</td>
<td></td>
</tr>
<tr>
<td>• OHS Training Procedure</td>
<td></td>
</tr>
<tr>
<td>Common Services, Occupational Health and Safety web page for advice, information and guidance on ionising radiation practices within the UoM.</td>
<td><a href="http://safety.unimelb.edu.au/topics/radiation/">http://safety.unimelb.edu.au/topics/radiation/</a></td>
</tr>
<tr>
<td>DRSO contact list</td>
<td><a href="http://safety.unimelb.edu.au/topics/radiation/drsos/">http://safety.unimelb.edu.au/topics/radiation/drsos/</a></td>
</tr>
<tr>
<td>Melbourne Policy Library:</td>
<td></td>
</tr>
<tr>
<td>• OHS Risk Management Procedure</td>
<td></td>
</tr>
<tr>
<td>The UoM web support for the risk assessment process, including 2-variable and 3-variable templates</td>
<td><a href="http://safety.unimelb.edu.au/tools/risk">http://safety.unimelb.edu.au/tools/risk</a></td>
</tr>
<tr>
<td>UoM radiation web page, including risk assessment templates</td>
<td><a href="http://safety.unimelb.edu.au/topics/radiation">http://safety.unimelb.edu.au/topics/radiation</a></td>
</tr>
<tr>
<td><strong>Standard Operating Procedures</strong></td>
<td><a href="http://safety.unimelb.edu.au/docs/SOPTemplate.doc">http://safety.unimelb.edu.au/docs/SOPTemplate.doc</a></td>
</tr>
<tr>
<td>UoM SOP template for developing SOPs or OHS work instructions.</td>
<td></td>
</tr>
<tr>
<td>Whilst the template has been developed for activities related to equipment/machinery it can be readily adapted for activities using ionising radiation materials.</td>
<td></td>
</tr>
<tr>
<td><strong>Purchasing</strong></td>
<td><a href="http://safety.unimelb.edu.au/publications/procedure/purchasing/">http://safety.unimelb.edu.au/publications/procedure/purchasing/</a></td>
</tr>
<tr>
<td>Melbourne Policy Library</td>
<td></td>
</tr>
<tr>
<td>• Purchasing – OHS Requirements Procedure</td>
<td></td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td><a href="http://www.arpansa.gov.au/Publications/Codes/rps2.cfm">http://www.arpansa.gov.au/Publications/Codes/rps2.cfm</a></td>
</tr>
<tr>
<td>The <em>Safety guide for the safe transport of radioactive material</em> (ARPANSA, 2008b) is additional guidance that can be used in conjunction with the <em>Code of practice for the safe transport of radioactive material</em> (ARPANSA, 2008a).</td>
<td><a href="http://www.arpansa.gov.au/pubs/rps/rps2_1.pdf">http://www.arpansa.gov.au/pubs/rps/rps2_1.pdf</a></td>
</tr>
</tbody>
</table>
11.7 REFERENCES


12 LABORATORY CERTIFICATION

12.1 DESCRIPTION

Laboratories using ionising radiation require UoM Ionising Radiation Laboratory Certification. The purpose of this certification is to ensure that the laboratory:

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

The certification process is undertaken by members of the Electromagnetic Radiation Safety Committee. Records of certification are maintained centrally by the Common Services, Occupational Health and Safety. Certification is undertaken on a biennial basis.

On successful certification a laboratory is issued with a “Laboratory Certification” sticker that can be attached near or on the doorway into the area.

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.

The supervisor/manager will be contacted by the local area DRSO or in some cases, staff from Common Services, Occupational health and Safety, advising them of the proposed certification date. At this time documents are provided to assist the local area prepare for certification including:

- Preparing for Radiation Safety Certification Inspection; and
- Radiation Safety Certification Checklist Ionising Radiation Laboratory.

12.2.1 Management

Certification of the management process includes:

- controlled authorised access to laboratory/area
- ionising radiation signs
- completed risk assessments
- completed standard operating procedures
- access to personnel exposure records
- tag out system in place
- suitable PPE available and used
- register of ionising radiation equipment
- department DRSO
- department radiation inventory
- purchasing approvals given
12.2.2 Laboratory Practices

Certification of the laboratory practices includes:
- radiation/contamination monitoring equipment available
- maintenance records of ionising equipment
- equipment calibration
- storage of ionising radiation
- labelling
- controls that reduce dose
- TLD available and used by all personnel
- authorised users list
- segregation of radioactive activities
- disposal pathways for radiation sources

12.2.3 Training

Certification of the training requirements includes:
- laboratory inductions completed for all personnel
- appropriate Radiation Safety Training prior to starting in the laboratory
- appropriate refresher training as required

12.2.4 Incident Reporting and Emergency Procedures

Certification of the incident reporting and emergency procedures includes:
- emergency procedures in place
- personnel aware of emergency procedures
- incident reporting procedures in place

12.2.5 Ionising Radiation and Sealed Sources

Certification of the ionising radiation and sealed sources requirements includes:
- 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 mapping surveys
- room design (including structure) takes into account shielding requirements
- plant hazard assessments of plant

12.3 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>UoM Radiation certification Checklist web page includes links to:</td>
<td></td>
</tr>
<tr>
<td>Laboratory Certification Inspection Checklist – Ionising Radiation Laboratory</td>
<td></td>
</tr>
<tr>
<td>UoM Radiation Safety Adviser</td>
<td><a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a></td>
</tr>
<tr>
<td>Common Services, Occupational Health and Safety radiation advice email address</td>
<td><a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a></td>
</tr>
</tbody>
</table>
13  FURTHER ADVICE AND ASSISTANCE

13.1  UoM Key Contacts and Assistance

Staff and students have a number of key resources at the UoM that they can contact for assistance with their ionising radiation enquiries. These include:

- Departmental Radiation Safety Officers
- University of Melbourne Radiation Safety Adviser
- Common Services, Occupational Health and Safety

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 UoM ionising radiation requirements. The DRSO should be the initial point of contact.

Contacts details are linked to the UoM web page “Radiation”. The address is:

http://safety.unimelb.edu.au/topics/radiation/drso/

13.1.2  University of Melbourne Radiation Safety Adviser

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

http://safety.unimelb.edu.au/about/contacts/common_chancellery.html#advice

13.1.3  Common Services, Occupational Health and Safety

Common Services, Occupational Health and Safety carry out a number of important functions with regards to ionising radiation including:

- maintaining the radiation Management Licence;
- mandating and maintaining the UoM ionising radiation requirements;
- providing ionising radiation training; and
- providing ionising radiation advice.

The contact email address is:

radiation-info@unimelb.edu.au

In addition Common Services, Occupational Health and Safety maintains the UoM safety web page “Radiation” (Figure 31). The web page address is:

http://safety.unimelb.edu.au/topics/radiation/
13.2 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Services, Occupational Health and Safety web site for advice, information and guidance on ionising radiation practices within the UoM (Figure 31)</td>
<td><a href="http://safety.unimelb.edu.au/topics/radiation/">http://safety.unimelb.edu.au/topics/radiation/</a></td>
</tr>
<tr>
<td>Common Services, Occupational Health and Safety radiation advice email address</td>
<td><a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a></td>
</tr>
<tr>
<td>Departmental Radiation Safety Officer contacts list</td>
<td><a href="http://safety.unimelb.edu.au/topics/radiation/drso/">http://safety.unimelb.edu.au/topics/radiation/drso/</a></td>
</tr>
</tbody>
</table>
14 LIST OF ABBREVIATIONS

ALARA As Low As Reasonably Achievable
ANSTO Australian Nuclear Science and Technology Organisation
ARPANSA Australian Radiation Protection and Nuclear Safety Association
AS Australian Standard
CPM Counts Per Minute
CPS Counts Per Second
DRSO Departmental Radiation Safety Officer
DPS Disintegrations Per Second
EHS Environment Health and Safety
EMR Electromagnetic Radiation
EPA Environmental Protection Society
ERSC Electromagnetic Radiation Safety Committee
HVL Half-Value Layer
IAEA International Atomic Energy Agency
ICRP International Commission of Radiological Protection
ISO International Organization for Standardization
LLE Loss of Life Expectancy
MSDS Material Safety Data Sheet
NHMRC National Health and Medical Research Council
OHSC Occupational Health and Safety Committee
PPE Personal Protective Equipment
SI (Système Internationale) International System of Units
SOP Standard Operating Procedure
TLD Thermoluminescent Dosimetry
TVL Tenth-Value Layer
UoM University of Melbourne
<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Radio-toxicity group</th>
<th>Half-life</th>
<th>Biological half-life</th>
<th>Max. energy of main beta rays MeV (% abundance)</th>
<th>Main gamma ray energy MeV (% abundance)</th>
<th>Gamma ray constant µSv/h</th>
<th>Most restrictive occupational inhalation ALI Bq</th>
<th>Occupational DAC (Note 1) Bq/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3 (gas)</td>
<td>4</td>
<td>12.3y</td>
<td>10d</td>
<td>0.018</td>
<td>---</td>
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<tr>
<td>H-3 (water Vapour)</td>
<td>4</td>
<td>20.38m</td>
<td></td>
<td>0.96 (98%) (positrons)</td>
<td>0.511 (200%)</td>
<td>194</td>
<td>---</td>
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<tr>
<td>H-3 (organically bound)</td>
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<td>5730y</td>
<td>12d</td>
<td>0.156 (100%)</td>
<td>---</td>
<td>---</td>
<td>3.4×10⁷ (2.5×10⁹)</td>
<td>1×10⁷</td>
</tr>
<tr>
<td>C-11</td>
<td>4</td>
<td>1.990</td>
<td>100%</td>
<td>1.520 (18%)</td>
<td>1.37 (100%)</td>
<td>1.0×10³</td>
<td>1.6×10⁴</td>
<td>---</td>
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<tr>
<td>C-11 (vapour)</td>
<td>4</td>
<td>0.540</td>
<td>97%</td>
<td>---</td>
<td>0.511 (100%)</td>
<td>---</td>
<td>1.0×10³</td>
<td>38×10⁶</td>
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<tr>
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<td>100%</td>
<td>---</td>
<td>1.270 (100%)</td>
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<td>C-11 dioxide</td>
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<td>99.9%</td>
<td>1.37 (100%)</td>
<td>2.750 (100%)</td>
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<td>4.2×10³</td>
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<tr>
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<td>---</td>
<td>---</td>
<td>2.9×10⁷</td>
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</tr>
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<td>---</td>
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<td>---</td>
<td>2.6×10³</td>
<td>---</td>
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<tr>
<td>F-18</td>
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<td>0.005</td>
<td>16%</td>
<td>1.100 (57%)</td>
<td>1.290 (43%)</td>
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<td>4.0×10³</td>
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<tr>
<td>Na-22</td>
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<td>97%</td>
<td>---</td>
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<td>---</td>
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<tr>
<td>Na24</td>
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<td>87d</td>
<td>100%</td>
<td>0.167 (100%)</td>
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<td>---</td>
<td>7.6×10³</td>
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<td>P-32</td>
<td>3b</td>
<td>90d</td>
<td>100%</td>
<td>1.37 (100%)</td>
<td>---</td>
<td>---</td>
<td>6.9×10³</td>
<td>---</td>
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<tr>
<td>P-33</td>
<td>3b</td>
<td>257d</td>
<td>100%</td>
<td>1.520 (18%)</td>
<td>1.300 (75%)</td>
<td>160</td>
<td>1.1×10⁴</td>
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</tr>
<tr>
<td>S-35 (inorganic)</td>
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<td>257d</td>
<td>100%</td>
<td>1.520 (18%)</td>
<td>1.300 (75%)</td>
<td>160</td>
<td>1.1×10⁴</td>
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<tr>
<td>S-35 (org. bound gas/vapour)</td>
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<td>87d</td>
<td>100%</td>
<td>1.520 (18%)</td>
<td>1.300 (75%)</td>
<td>160</td>
<td>1.1×10⁴</td>
<td>---</td>
</tr>
<tr>
<td>K-42</td>
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<td>3.52 (82%)</td>
<td>20%</td>
<td>1.520 (18%)</td>
<td>1.300 (75%)</td>
<td>160</td>
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<td>---</td>
</tr>
<tr>
<td>Ca-45</td>
<td>3a</td>
<td>163d</td>
<td>45y</td>
<td>0.260 (99.9%)</td>
<td>1.300 (75%)</td>
<td>160</td>
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</tr>
<tr>
<td>Ca-47</td>
<td>3a</td>
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<td>100%</td>
<td>1.520 (18%)</td>
<td>1.300 (75%)</td>
<td>160</td>
<td>1.1×10⁴</td>
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<tr>
<td>Sc-47</td>
<td>3b</td>
<td>3.351d</td>
<td>100%</td>
<td>0.440 (68%)</td>
<td>0.159 (68%)</td>
<td>22 6.3</td>
<td>1.1×10⁴</td>
<td>---</td>
</tr>
<tr>
<td>Cr-51</td>
<td>4</td>
<td>2.700</td>
<td>97%</td>
<td>0.470 (53%)</td>
<td>1.100 (57%)</td>
<td>180</td>
<td>2.3×10⁴</td>
<td>---</td>
</tr>
<tr>
<td>Fe-55</td>
<td>3b</td>
<td>200d</td>
<td>100%</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>9.1×10³</td>
<td>---</td>
</tr>
<tr>
<td>Fe-59</td>
<td>3a</td>
<td>700d</td>
<td>100%</td>
<td>0.470 (53%)</td>
<td>1.100 (57%)</td>
<td>180</td>
<td>2.6×10³</td>
<td>---</td>
</tr>
</tbody>
</table>

APPENDIX A: PROPERTIES OF COMMONLY USED RADIONUCLIDES

The following has been adapted from Standards Association of Australia, 1998. Safety in laboratories. Part 4. Ionizing radiations, (AS 2243.4 1998), Standards Australia, North Sydney.
<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Radio-toxicity group +</th>
<th>Half-life</th>
<th>Biological half-life</th>
<th>Max. energy of main beta rays MeV (% abundance)</th>
<th>Main gamma ray energy MeV (% abundance)</th>
<th>Gamma ray constant µSv/h $\dagger$</th>
<th>Most restrictive occupational inhalation ALI Bq</th>
<th>Occupational DAC (Note 1) Bq/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-57</td>
<td>3b</td>
<td>271d</td>
<td>9.5d</td>
<td>---</td>
<td>0.122 (86%) 0.136 (10%)</td>
<td>41</td>
<td>3.3×10⁷</td>
<td>1.4×10⁴</td>
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<tr>
<td>Co-58</td>
<td>3b</td>
<td>71d</td>
<td>9.5d</td>
<td>0.475 (14.8%) (positrons)</td>
<td>0.511 (29.8%) 0.810 (99%)</td>
<td>170</td>
<td>1.2×10⁷</td>
<td>4.9×10³</td>
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<tr>
<td>Co-60</td>
<td>3</td>
<td>2.53y</td>
<td>9.5d</td>
<td>0.318 (100%)</td>
<td>1.170 (100%) 1.350 (100%)</td>
<td>370</td>
<td>1.2×10⁶</td>
<td>4.9×10²</td>
</tr>
<tr>
<td>Cu-64</td>
<td>4</td>
<td>12.58h</td>
<td></td>
<td>0.578 (37%) (positrons) 0.653 (18%)</td>
<td>0.511 (35.7%)</td>
<td>36</td>
<td>1.3×10⁶</td>
<td>5.6×10⁴</td>
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<tr>
<td>Cu-67</td>
<td>3b</td>
<td>61.7h</td>
<td>3.78d</td>
<td>0.390 (56%)</td>
<td></td>
<td>24</td>
<td>3.4×10⁷</td>
<td>1.4×10⁷</td>
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<tr>
<td>Zn-65</td>
<td>3a</td>
<td>244d</td>
<td>933d</td>
<td>---</td>
<td>1.115 (50.7%)</td>
<td>89</td>
<td>7.1×10⁷</td>
<td>3.0×10⁷</td>
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<tr>
<td>Ga-67</td>
<td>3b</td>
<td>3.26d</td>
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<td>---</td>
<td>0.092 (35.7%)</td>
<td>30</td>
<td>7.1×10⁷</td>
<td>3.0×10⁷</td>
</tr>
<tr>
<td>Ga-68</td>
<td>4</td>
<td>67.7m</td>
<td>6d</td>
<td>1.900 (88%)</td>
<td>0.511 (178%)</td>
<td>179</td>
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<td>1.0×10⁷</td>
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<tr>
<td>Ge-68</td>
<td>2</td>
<td>288d</td>
<td></td>
<td>---</td>
<td>0.020 (67.7%)</td>
<td>16</td>
<td>2.5×10⁶</td>
<td>1.1×10⁷</td>
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<tr>
<td>Se-75</td>
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<td>0.265 (59.8%)</td>
<td>230</td>
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<td>4.9×10⁴</td>
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<tr>
<td>Br-82</td>
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<td>1.47d</td>
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<td>440</td>
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<td>9.5×10³</td>
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<tr>
<td>Rb-86</td>
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<td>18.7d</td>
<td>45d</td>
<td>0.697 (8.8%) 1.774 (91.2%)</td>
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<td>15</td>
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<td>6.4×10³</td>
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<tr>
<td>Sr-89</td>
<td>3a</td>
<td>50.5d</td>
<td>1.8 x 10¹d</td>
<td>1.49 (100%)</td>
<td>---</td>
<td>---</td>
<td>3.6×10⁷</td>
<td>1.5×10⁷</td>
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<tr>
<td>Sr-90</td>
<td>2</td>
<td>29y</td>
<td>50y</td>
<td>2.280 (Note 2)</td>
<td>---</td>
<td>---</td>
<td>2.6×10⁷</td>
<td>1.1×10⁷</td>
</tr>
<tr>
<td>Y-90</td>
<td>3b</td>
<td>2.67d2</td>
<td>49y</td>
<td>0.280 (100%)</td>
<td>---</td>
<td>---</td>
<td>1.2×10⁷</td>
<td>4.9×10⁴</td>
</tr>
<tr>
<td>Mo-99</td>
<td>3b</td>
<td>2.8d</td>
<td></td>
<td>0.436 (17%) 1.210 (83%)</td>
<td>0.74 (13%)</td>
<td>31</td>
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<td>7.6×10³</td>
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<tr>
<td>Tc-99m</td>
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<td>6.0h</td>
<td>20d</td>
<td>0.14 (89%)</td>
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<td>33</td>
<td>6.9×10⁷</td>
<td>2.9×10⁷</td>
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<tr>
<td>Cd-109</td>
<td>2</td>
<td>462d</td>
<td>9000d</td>
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<td>50</td>
<td>2.1×10⁷</td>
<td>8.7×10⁴</td>
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<td>In-111</td>
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<td>2.8d</td>
<td>Indefinite</td>
<td>---</td>
<td>0.245 (94%) 0.171 (90%)</td>
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<td>2.7×10⁴</td>
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<tr>
<td>I-123</td>
<td>4</td>
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<td>138d</td>
<td>---</td>
<td>0.159 (93.4%)</td>
<td>75</td>
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<td>I-124</td>
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<td>0.027 (30%) 0.511 (46%) 0.603 (59%)</td>
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<td>I-125</td>
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<td>138d</td>
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<td>1.1×10⁷</td>
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<td>I-131</td>
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<td>8d</td>
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<td>0.360 (81.2%)</td>
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<td>7.6×10⁴</td>
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<td>0.670 (98.7%)</td>
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<td>3.4×10⁴</td>
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<td>70d</td>
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<td>0.660 (Note 2) 103 (Note 2)</td>
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<td>5.6×10⁴</td>
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<td>Nuclide</td>
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<td>Biological half-life</td>
<td>Max. energy of main beta rays</td>
<td>Main gamma ray energy</td>
<td>Gamma ray constant</td>
<td>Most restrictive occupational inhalation ALI</td>
<td>Occupational DAC (Note 1)</td>
</tr>
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<td></td>
<td>group +</td>
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<td>MeV</td>
<td>MeV</td>
<td>µSv/h</td>
<td>Bq</td>
<td>Bq/m³</td>
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<td>Sm-153</td>
<td>3b</td>
<td>46.7h</td>
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<td>0.690 (43%) 0.640 (35%)</td>
<td>0.103 (28%)</td>
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<td>2.9×10⁷</td>
<td>1.2×10⁴</td>
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<tr>
<td>Dy-165</td>
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<td>2.33h</td>
<td></td>
<td>1.19 (14%) 1.29 (83%)</td>
<td>---</td>
<td>6.2</td>
<td>2.3×10⁴</td>
<td>9.6×10³</td>
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<tr>
<td>Yb-169</td>
<td>3a</td>
<td>32.0d</td>
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<td>0.540 (41%) 0.670 (48%)</td>
<td>0.320 (82.8%)</td>
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<td>4.1×10³</td>
<td>1.7×10³</td>
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<tr>
<td>Ir-192</td>
<td>3a</td>
<td>74d</td>
<td>20d</td>
<td>0.960 (98.8%)</td>
<td>0.410 (95.5%)</td>
<td>79</td>
<td>1.8×10³</td>
<td>7.6×10³</td>
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<tr>
<td>Au-198</td>
<td>3b</td>
<td>2.7d</td>
<td>120d</td>
<td>---</td>
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<tr>
<td>Ti-201</td>
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<td>0.167 (10%)</td>
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<tr>
<td>Ra-226</td>
<td>2</td>
<td>1600y</td>
<td>1.64×10⁹d</td>
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<td>---</td>
<td>3.2</td>
<td>9.1×10⁷</td>
<td>3.8×10⁵</td>
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<tr>
<td>Am-241</td>
<td>1</td>
<td>432y</td>
<td>50y</td>
<td>---</td>
<td>0.0139 (42.7%) 0.060 (35.9%)</td>
<td>85</td>
<td>7.4×10³</td>
<td>3.1×10⁻¹</td>
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<tr>
<td>Sr-90+Y-90</td>
<td>2</td>
<td>29y</td>
<td>49y</td>
<td>2.28</td>
<td>---</td>
<td>---</td>
<td>5.1×10⁷</td>
<td>2.1×10⁹</td>
</tr>
<tr>
<td>Ra-226+d (Note 3)</td>
<td>2</td>
<td>1600y</td>
<td>3.27 (Note 2) 0.8 (Note 4)</td>
<td>223</td>
<td>5.0×10⁷</td>
<td>2.1×10⁹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Th metal (freshly chemically separated thorium – Th-232 + Th-228)</td>
<td>4</td>
<td>1.4×10¹⁰y</td>
<td>6.6×10² 2.7×10⁻¹ 1.3×10⁵</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Th-ore (Note 5)</td>
<td>4</td>
<td>--</td>
<td>340 (Note 6) 3.1×10³ (Note 7) 1.3×10⁰</td>
<td></td>
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</tr>
<tr>
<td>U metal (freshly chemically separated uranium – U-238 + U-234)</td>
<td>4</td>
<td>4.5×10⁹y</td>
<td>3.2×10³ 1.3×10⁰ 4.3×10⁵</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-ore (Note 5)</td>
<td>4</td>
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<td>150 (Note 8) 3.5×10³ 1.5×10⁰</td>
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<td></td>
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</tr>
</tbody>
</table>
FOOTNOTES:

* 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 m³ 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


