The University of Melbourne

Safe Radiation Practices – Ionising

Training Guide
About This Booklet

This booklet is used in conjunction with other Safe Radiation Practices training materials prepared by the authors.

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 TRAINING GUIDE

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

The training guide is intended to be used in conjunction with the UoM in-house training series Safe Radiation Practices. In addition it can be used as an ongoing reference guide for personnel following the completion of their training.

The training guide supports performance criteria for ionising radiation training packages contained in the Safe Radiation Practices series. Relevant training packages from this series include:

- Safe Radiation Practices – Ionising
- Safe Radiation Practices – Ionising (Neutron Probe)
- Safe Radiation Practices – Ionising (Departmental Radiation Safety Officers)

See Section 11.1 for additional information on UoM ionising radiation training.

1.2 BRIEF HISTORY

Uranium was the first radioactive element to be discovered in 1789 by Martin Heinrich Klaproth. In 1896 more than 100 years after Klaproth’s discovery, Antoine Becquerel identified its radioactive properties. One year prior to this (1895) Wilhelm Röntgen 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 Röntgen’s hand taken by Wilhelm Röntgen in 1895 (University of Iowa. Hospitals & Clinics, 2006)

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)**
1.3 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
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<tbody>
<tr>
<td>Radiation oncology: a century of achievements (Bernier,</td>
<td>Instructions:</td>
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<td>Hall &amp; Giaccia, 2004) The full journal article is available</td>
<td>1. Log on to University Library Supersearch. Link:</td>
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<td>from the UoM “e-Journal” link. It is accessed through</td>
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<td>University Library Supersearch.</td>
<td>2. Log-on to Supersearch and access the journal through “Find e-Journal”.</td>
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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 at both Commonwealth and State with several Government authorities responsible for their oversight and administration.

2.1 COMMONWEALTH GOVERNMENT

Commonwealth radiation legislation is administered by the Australian Nuclear Science and Technology Organisation (ANSTO) and includes:
- Australian Radiation Protection and Nuclear Safety Act 1998 (Australian Government, 2008); 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 determined radioactive sealed sources that have been identified as possible use in terrorist activities.

2.2 VICTORIAN GOVERNMENT

2.2.1 Ionising Radiation Legislation

State radiation legislation is administered by the Department of Health, Radiation Safety Unit and includes:
- Radiation Act 2005 (Victorian Government, 2005); and

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

Radiation legislation also requires:
- all personnel who use radiation in their work to be individually licensed; however exemptions are granted provided that a licensee supervises the work;
- all laboratories to comply with the applicable legislative requirements; and
- all personnel working with a radiation sources shall receive training appropriate to the nature of tasks undertaken.
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.

2.2.3 Radiation Management Licence

The Radiation Act 2005 (Victorian Government, 2005) defines a radiation source to mean:

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

Radioactive materials spontaneously emit radiation and are normally described as open or closed sources. 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.

The different categories of radiation sources each have their own advantages, disadvantages and usages (Table 1). 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.

<table>
<thead>
<tr>
<th>Open Sources</th>
<th>Closed Sources</th>
<th>Ionising Radiation Apparatus</th>
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<tbody>
<tr>
<td>Examples</td>
<td>³H, ¹⁴C, ³⁵S, ³²P, ³³S,¹²⁵I</td>
<td>⁶⁰Co, ¹³⁷Cs, ²²⁶Ra</td>
</tr>
<tr>
<td>Advantages</td>
<td>Used in small quantities</td>
<td>No Internal contamination</td>
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<tr>
<td></td>
<td>Easy to shield</td>
<td>No Half life worries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Waste disposal problems</td>
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<tr>
<td>Disadvantages</td>
<td>Half life</td>
<td>Potential Large Dose</td>
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<td></td>
<td>Spills</td>
<td>Half life</td>
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<td></td>
<td>Internal contamination</td>
<td>Shielding</td>
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<td>Waste disposal</td>
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<td>Physical Sciences</td>
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Table 1: Categories of radiation sources including their advantages, disadvantages and common usages

The Radiation Act 2005 (Victorian Government, 2005) requires the UoM to hold a Radiation Management Licence for the possession and use of all radiation sources.

The Radiation Management Licence is centrally controlled and maintained by the UoM Radiation Safety Advisor (UoM RSA) on behalf of the General Manager, OHS and Injury Management. This includes:

• maintaining an inventory of all radiation sources used by the UoM; and
• coordinating modifications to the current licence – such as acquisition and disposal of ionising radiation apparatus.

Additional Closed Sources or Ionising Radiation Apparatus

When a local area acquires additional closed sources or ionising radiation apparatus that are not listed on the Radiation Management Licence the Victorian Regulator must be notified. This means that before any additional closed sources or ionising radiation apparatus can be put into service the following is required:

• a Notice of Acquisition; and
• an Application to Vary a Management Licence.
The process is managed by the UoM RSA. Therefore when a local area decides to acquire additional ionising radiation apparatus they must contact the UoM RSA.

The above process is also applicable for the disposal of closed sources or ionising radiation apparatus. In this instance a Notice of Disposal and an Application to Vary a Management Licence are required.

**Additional Open Sources**

When a local area decides to acquire additional open sources that are not listed on the Radiation Management Licence the Victorian Regulator must be notified. This means that before any additional open source can be put into service an Application to Vary a Management Licence is required.

The process is managed by the UoM RSA. Therefore when a local area decides to acquire additional open sources they must contact the UoM RSA.

**Schedules**

The Radiation Management Licence is divided into Schedules that distinguish radiation sources and their uses into 10 groups. Due to the UoM ionising radiation activities there are eight schedules relevant to the UoM Radiation Management Licence (Table 2).

Each Schedule in the UoM Radiation Management Licence has specific mandated conditions. These include complying with Department of Health documents, ARPANSA Radiation Protection Series publications and Radiation Health Series publications. These conditions have been included in Table 2 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 and in particular Schedule 1. This publication is referred to in all ARPANSA Radiation Protection Series Publications and therefore is considered, by the UoM to also be a general condition of the UoM Radiation Management Licence.

The *Code of practice security of radioactive sources 2007, Radiation Protection Series Publication No. 11* (ARPANSA, 2007) is not included in the UoM Radiation Management Licence. It is the intention of the Regulator to include this Code in the future. This Code is relevant to all sealed sources (Schedule 3 and Schedule 4) therefore this has been taken into account when developing UoM policy and procedures for securing radiation sources.

<table>
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<tr>
<th>Schedule</th>
<th>Description</th>
<th>Conditions</th>
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<tbody>
<tr>
<td>1</td>
<td>The general conditions</td>
<td>The general conditions that apply to the entire licence • <em>Radiation incidents reporting requirements</em> (Department of Human Services, 2007a)</td>
</tr>
<tr>
<td>2</td>
<td>Radiation practices involving ionising radiation apparatus</td>
<td>Analysis of materials (x-ray analysis equipment) • <em>Code of practice for protection against ionizing radiation emitted from x-ray analysis equipment, Radiation Health Series No. 9</em> (NHMRC, 1985)</td>
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<td>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</em>, Radiation Health Series No. 21 (NHMRC, 1987)</td>
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<td></td>
<td>Dentistry – Researched based practices involving irradiation of humans • <em>Code of practice radiation protection in dentistry 2005, Radiation Protection Series Publication No. 10</em> (ARPANSA, 2005a) Also referred to in RPS Publication No. 10 is:</td>
</tr>
<tr>
<td>Schedule</td>
<td>Description</td>
<td>Conditions</td>
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|          |             | - 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)  
|          | Medical – Research based practices involving irradiation of humans |  
- Recommendations for the discharge of patients undergoing treatment with radioactive substances 2002, Radiation Protection Series Publication No. 4 (ARPANSA, 2002)  
- 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)  |
|          | Veterinary |  
- Code of practice for the safe transport of radioactive material 2008, Radiation Protection Series Publication No. 2 (ARPANSA, 2008b)  |
| 3        | Radiation practices involving sealed source apparatus |  
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 |  
- Code of practice for the safe transport of radioactive material 2008, Radiation Protection Series Publication No. 2 (ARPANSA, 2008b)  |
|          | Education and research not involving the exposure of humans to ionising radiation |  
- Code of practice for the safe transport of radioactive material 2008, Radiation Protection Series Publication No. 2 (ARPANSA, 2008b)  |
|          | Calibration of instrumentation |  
- Code of practice for the safe transport of radioactive material 2008, Radiation Protection Series Publication No. 2 (ARPANSA, 2008b)  |
| 5        | Radiation practices involving radioactive material |  
- Code of practice for the safe transport of radioactive material 2008, Radiation Protection Series Publication No. 2 (ARPANSA, 2008b)  
- Radioactive material disposal requirements (Department of Human Services, 2007b)  
- Recommendations for the discharge of patients undergoing treatment with radioactive substances 2002, Radiation Protection Series Publication No. 4 (ARPANSA, 2002)  |
|          | Education and research not involving the exposure of humans to ionising radiation |  
- Code of practice for the safe transport of radioactive material 2008, Radiation Protection Series Publication No. 2 (ARPANSA, 2008b)  
- Radioactive material disposal requirements (Department of Human Services, 2007b)  |
|          | Use of ionising radiation apparatus for education and research purposes |  
- Code of practice for the safe transport of radioactive material 2008, Radiation Protection Series Publication No. 2 (ARPANSA, 2008b)  
- Radioactive material disposal requirements (Department of Human Services, 2007b)  |

2 RPS No. 4 has been included as a condition of Schedule 5 radioactive materials the UoM Radiation Management Licence although these activities do not include exposure to humans.
<table>
<thead>
<tr>
<th>Schedule</th>
<th>Description</th>
<th>Conditions</th>
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</table>
|          | Diagnostic veterinary nuclear medicine                                       | • Code of practice and safety guide for radiation protection in veterinary medicine 2009, Radiation Protection Series Publication No. 17 (ARPANSA, 2009)  
• Code of practice for the safe transport of radioactive material 2008, Radiation Protection Series Publication No. 2 (ARPANSA, 2008b)  
• Radioactive material disposal requirements (Department of Human Services, 2007b) |
| 6        | Radiation practices involving procuring, arranging or conducting research involving irradiation of persons |                                                                                                                                                                                                          |
• Recommendations for the discharge of patients undergoing treatment with radioactive substances 2002, Radiation Protection Series Publication No. 4 (ARPANSA, 2002)  
• 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 2007 (NHMRC, 2007) |
| 7        | Radiation practices involving non-ionising radiation sources                |                                                                                                                                                                                                          |
| 8        | Radiation practices involving sale of radiation sources                     |                                                                                                                                                                                                          |
| 9        | Radiation practices involving transport of radioactive material             |                                                                                                                                                                                                          |
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) |
| 10       | [No heading]                                                                |                                                                                                                                                                                                          |
|          | List of the radiation sources which the licence holder (UoM) has stated as being in their possession.  
These are sources from Schedule 2, Schedule 3 and Schedule 4 (it does not include Schedule 5). |                                                                                                                                                                                                          |

Table 2: Radiation Management Licence schedules and the specific legal conditions for the UoM

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

2.2.4 Safety Legislation

State 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.
2.3 ADVISORY BODIES

2.3.1 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.

2.3.2 International Commission on Radiological Protection

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

2.3.3 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 system.

2.3.4 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."

2.4 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 is available from:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Select the “Victorian Law Today” icon in the web link</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>
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<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</td>
<td>Instructions:</td>
</tr>
<tr>
<td>Standards. They can be accessed through the University Library Supersearch. A UoM user name</td>
<td>1. Log-on to the University Library Supersearch. Link:</td>
</tr>
<tr>
<td>and password is required.</td>
<td><a href="http://www.library.unimelb.edu.au/">http://www.library.unimelb.edu.au/</a></td>
</tr>
<tr>
<td></td>
<td>2. Log-on to Supersearch and access the Standards through SAI Global – Australian Standards.</td>
</tr>
</tbody>
</table>

2.5 REFERENCES


3 UNIVERSITY OF MELBOURNE REQUIREMENTS

The UoM is required to 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 provides a safe and healthy environment for all personnel working with radiation sources.

3.1 POLICY AND PROCEDURE

The UoM OHS ionising radiation requirements are described in the:
- Ionising Radiation Risk Management (UOM 324) procedure; and
- Ionising Radiation Management Plan.

The procedure and plan are located in the Melbourne Policy Library. Currently the Ionising Radiation Management Plan is embedded in the procedure.

3.2 RESPONSIBILITIES

Within areas controlled by the UoM where ionising material is used, a clearly defined chain of responsibility shall be specified with the duties and responsibilities of individual persons clearly set out in writing. UoM senior management, such as Head of Budget Division, is responsible for providing and maintaining resources necessary to implement the Ionising Radiation Management Plan.

3.2.1 Manager/Supervisor

The manager/supervisor must protect personnel from radiation sources by:
- providing a safe place of work, including a high standard of radiation protection;
- ensuring appropriate safety procedures are established and observed;
- complying with the relevant legislation;
- observing recommendations of relevant Codes of Practice, Standards and other written guidance provided by the regulatory authorities;
- providing appropriate training, before commencement of work, to personnel engaged in work with radiation sources;
- providing refresher training at appropriate intervals;
- providing personnel working with radiation sources with personal monitoring equipment;
- ensuring dose records are maintained and made available to each person and the regulatory authority;
- ensuring radiation monitoring instruments are provided and are appropriately maintained and calibrated;
- ensuring irradiating apparatus and radioactive sources are regularly checked and maintained; and
- ensuring records required by the regulatory authority are maintained and available.

3.2.2 University of Melbourne Radiation Safety Adviser

The University of Melbourne Radiation Safety Adviser (UoM RSA) is responsible for:
- providing guidance to the Head of Budget Division on the appointment of a Departmental Radiation Safety Officers (DRSO);
- advising and providing guidance to DRSO;
- advising UoM management and personnel on safe working practices in accordance with relevant legislation, Codes of Practice and Standards;
- liaising with the relevant regulatory authorities;
- ensuring that UoM licensing and registration matters are processed;
- inspecting, providing recommendations and reports on proposed and ionising radiation installs;
• recording and reporting “radiological incidents” to the regulatory authority;
• providing guidance on emergency procedures for possible radiological incidents;
• advising on the safe storage of radiation sources;
• providing guidance on the disposal of radioactive waste (where applicable); and
• providing ionising radiation training.

3.2.3 Departmental Radiation Safety Officer

The Head of Budget Division, taking into account guidance from the UoM RSA, is responsible for appointing the Departmental Radiation Safety Officer (DRSO). The DRSO is responsible for:
• liaising with the UoM RSA;
• advising Departments on safe working practices in accordance with relevant legislation, Codes of Practice and Standards;
• liaising with Department management on radiation issues;
• ensuring that all necessary Department licensing and registration matters are processed;
• arranging for local area, equipment and operations be monitored where applicable;
• ensuring that suitable monitoring devices are provided and kept in good working order, properly used, and calibrated as required;
• arranging for records of effective doses to be made available to staff;
• reporting to Departmental management and the UoM RSA any radiological incidents;
• preparing emergency procedures for any foreseeable radiological incidents;
• ensuring that current records of stocks and locations of radiation sources are maintained and kept for two years after the date of disposal;
• arranging for the safe storage of radiation sources and for the safe disposal of any radioactive waste; and
• providing advice and instruction to personnel, on ionising radiation safety in an easily understandable form.

3.2.4 Personnel

Personnel (staff, students and others) are required to observe all local safe working instructions. In particular, all personnel working with ionising radiation shall not expose themselves or others to radiation to an extent greater than is absolutely necessary for the purposes of the work, and shall ensure that any doses received do not exceed the UoM specified dose limits.

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

The above responsibilities were adapted from a number of resources including:
• Ionising Radiation Risk Management (UOM 324) procedure;
• Ionising Radiation Management Plan;
• Radiation safety officer – Typical duties (Department of Human Services, nd)

3 Refer to Section 9.1 for a definition of a radiological incident.
3.3 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 General Manager Occupational Health & Safety and Injury Management to be tabled at the Occupational Health and Safety Committee (OHSC).

3.4 Dose Limits

3.4.1 General

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, 2007).

The dose limits of ionising radiation received by personnel as a result of work with radiation sources shall not exceed the dose limits published in the National standard for limiting occupational exposure to ionizing radiation, [NOHSC:1013(1995)] (ARPANSA, 2002). These dose limits are based on the recommendations from The recommendations of the International Commission on Radiological Protection (ICRP, 2007).

3.4.2 Occupational and Public Dose Limits


<table>
<thead>
<tr>
<th>Application</th>
<th>Occupational Dose limit</th>
<th>Public Dose limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>effective dose⁴</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>50 mSv</td>
</tr>
</tbody>
</table>

Table 3: Occupational and general public dose limits mandated by the Radiation Regulations 2007 (Victorian Government, 2007)

⁴ Effective dose is defined in Section 4.7.6.
3.5 Sourcing Further Information

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melbourne Policy Library:</td>
<td></td>
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<tr>
<td>• Ionising Radiation Risk Management (UOM 324); and</td>
<td><a href="http://policy.unimelb.edu.au/UOM0324">http://policy.unimelb.edu.au/UOM0324</a></td>
</tr>
<tr>
<td>• Ionising Radiation Management Plan</td>
<td></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>
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<tr>
<td>The web site is under currently under construction.</td>
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<td>Electromagnetic Radiation Safety Committee web page:</td>
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<td>• meeting calendar</td>
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</tr>
<tr>
<td>• membership</td>
<td></td>
</tr>
<tr>
<td>• minutes</td>
<td></td>
</tr>
<tr>
<td>• Terms of Reference</td>
<td></td>
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<td>Health &amp; Safety Common Services radiation advice email address</td>
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</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>

3.6 References


Note

UoM policy requires that ionising radiation work practices undertaken at the UoM shall limit total whole body exposure of all personnel 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
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 $1.6929 \times 10^{-27}$ 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 longer-wavelength ultraviolet and shorter-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 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 wave lengths 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 ionising radiation produced by subatomic particles (protons, neutrons and electrons).

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 from 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.

Neutrons

Neutron particles are released when a radioactive atom disintegrates. They are uncharged nuclear particles classified depending upon their energy into either thermal neutrons or slow neutrons. Neutrons have an energy range of approximately 0.04 eV to 1 MeV.

The neutron was discovered by James Chadwick in 1932.

5 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.
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 RADIOACTIVE ISOTOPE

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

Example

Compare three radioactive isotopes for cobalt (Co): ⁵⁷Co, ⁵⁸Co and ⁶⁰Co.

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

- ⁵⁷Co — 30 neutrons
- ⁵⁸Co — 31 neutrons
- ⁶⁰Co — 33 neutrons

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

4.5 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 decadic⁶ 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).

⁶ In mathematics, decadic refers to the logarithmic scale to the base ten.
4.6 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:

- $^{238}\text{U}$;
- $238\text{U}$;
- $\text{U}^{238}$; and
- $\text{U}-238$.

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

- Appendix A; and
- Figure 8.

4.7 MEASURING RADIATION

4.7.1 Activity

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

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).
Curie Ci | Becquerel Bq | dps | cpm
--- | --- | --- | ---
1 | $37 \times 10^9 (3.7 \times 10^{10})$ | $37 \times 10^9 (3.7 \times 10^{10})$ | $2.22 \times 10^{12}$
0.1 (100 mCi) | $3.7 \times 10^8$ | $3.7 \times 10^8$ | $2.22 \times 10^{11}$
0.01 (10 mCi) | $3.7 \times 10^7$ | $3.7 \times 10^7$ | $2.22 \times 10^{10}$
0.001 (1 mCi) | $3.7 \times 10^6$ | $3.7 \times 10^6$ | $2.22 \times 10^9$
0.0001 (100 μCi) | $3.7 \times 10^5$ | $3.7 \times 10^5$ | $2.22 \times 10^8$

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>
<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 sq metre 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 sq metre 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>

Table 7: Examples of radiological activity in the everyday environment

4.7.2 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 7).

Electron volts are normally expressed in keV or MeV.

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).
4.7.3 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.

4.7.4 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:

\[
1 \text{ Gy} = 1.0 \text{ J/kg}
\]

4.7.5 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\(^7\) \((W_R)\) 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

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 = \text{equivalent dose} \quad D = \text{average absorbed dose in the organ} \quad W_R = \text{radiation weighting factor} \]

**Example**

Compare 50 mGy 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: \( H = 50 \times 10^{-3} \times 1 = 50 \times 10^{-3} = 0.05 \text{ Sv} \)

### 4.7.6 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.

\(^7\) The radiation weighting factor is also referred to as the radiation quality factor.
Former Weighting Factors for Organs and Tissues

<table>
<thead>
<tr>
<th>Organs 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)

The current tissue weighting factors (Table 10) and are listed in ICRP Publication 103 (ICRP, 2007).

Current Weighting Factors for Organs and Tissues

<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
4.7.7 Dose Rate

The unit of measurement of dose rate is the: sievert (Sv) per unit of time.

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

Example

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

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

4.7.8 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</td>
<td>coulomb per kilogram</td>
<td>C/kg</td>
<td>roentgen</td>
<td>R</td>
<td>(1 \text{C/kg} = 3876 \text{ R})</td>
</tr>
<tr>
<td>absorbed dose</td>
<td>gray</td>
<td>Gy</td>
<td>rad</td>
<td>r</td>
<td>(1 \text{ Gy} = 100 \text{ r})</td>
</tr>
<tr>
<td>equivalent dose</td>
<td>sievert</td>
<td>Sv</td>
<td>rem(^8)</td>
<td>rem</td>
<td>(1 \text{ Sv} = 100 \text{ rem})</td>
</tr>
<tr>
<td>effective dose</td>
<td>sievert</td>
<td>Sv</td>
<td>rem</td>
<td>rem</td>
<td>(1 \text{ Sv} = 100 \text{ rem})</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>(1 \text{ Sv/h} = 100 \text{ rem/h})</td>
</tr>
</tbody>
</table>

Table 11: Summary and comparison of radiation SI units with the old radiation units

---

\(^8\) Rem stands for roentgen equivalent man.

Example

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

Therefore:

For the lungs: \(E = 2 \times 0.12 = 0.24 \text{ mSv}\)
For the thyroid \(E = 1 \times .04 = 0.04 \text{ mSv}\)
The effective dose \(0.25 + 0.04 = 0.29 \text{ mSv}\)
4.8 RADIOACTIVE DECAY

4.8.1 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 $^{238}\text{U}$ (Uranium 238) has an unstable nucleus. Due to radioactive decay $^{238}\text{U}$ changes through many different isotopes until it finally becomes the stable element of lead (Figure 8).

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

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

### Example

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

Each radioactive isotope has its own unique half-life. These can vary from fractions of a second to several billion years. For example compare two uranium isotopes $^{235}\text{U}$ and $^{238}\text{U}$. The half-life of $^{235}\text{U}$ is 713,000,000 years and the half-life of $^{238}\text{U}$ 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 9), then its activity can be calculated at another point in time. The equation is:

\[ A_t = \frac{A_0}{2^n} \]

\( A_t \) = activity at a given time \hspace{2mm} \( A_0 \) = original activity \hspace{2mm} \( n \) = number of half-lives

**Example**

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:

\[ \frac{365}{14.3} \] which equals 25.5 half-lives

**Therefore:**

\[ n = 25.2, \quad A_0 = 37 \text{ GBq} \]

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

\[ = 37 \times 10^9/47453133 \text{ Bq} \]

\[ = 3.7 \times 10^7 \times 10^8 \text{ Bq} \]

\[ = 778 \text{ Bq} \]

Figure 9: Graphical representation of radioactive half-life (HyperPhysics, 2010)

### 4.9 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.
4.10 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 10). 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 10: Annual Australian per capita radiation dose from natural and medical sources (ARPANSA, 2008)](image)

Background ionising radiation levels (from natural radiation sources) in Australia are relatively small in comparison to the other countries (Figure 11). 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.
4.11 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Ptable</em> (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</td>
<td></td>
</tr>
<tr>
<td>periodic table. In addition to chemical properties, there</td>
<td></td>
</tr>
<tr>
<td>is also a function that describes the physical (radiological</td>
<td></td>
</tr>
<tr>
<td>isotopes) properties of chemical elements.</td>
<td></td>
</tr>
<tr>
<td><em>The language of the nucleus</em> (Scientific Digital Visions</td>
<td><a href="http://www.nuclearglossary.com/suites/nuclearglossary_">http://www.nuclearglossary.com/suites/nuclearglossary_</a></td>
</tr>
<tr>
<td>Inc., 2006)</td>
<td>radioactive_decay.html</td>
</tr>
<tr>
<td>A web resource that provides a glossary of radioactive</td>
<td></td>
</tr>
<tr>
<td>terms</td>
<td></td>
</tr>
</tbody>
</table>

4.12 REFERENCES


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 cellular 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 at a cellular level (Figure 12) may include:
• cell death
• free radicals
• chromosomal aberrations;
• mutations; and
• genomic instability.

Figure 12: Possible cellular\(^9\) damage from exposure to radiological material

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

5.2 PHYSICAL FACTORS

The physical factors that influence the effects of ionising radiation include:
• the type, energy and dose of the ionising radiation;
• the dose rate;
• 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.

\(^9\) Cellular 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 radioactive 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 (radioactive half-life) and biological excretion (biological half-life). Tuszynski and Dixon (2001) demonstrates this relationship with a number of radioisotopes (Table 12).

<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 10^3)</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>(^{37})Cl</td>
<td>(1.1 \times 10^{12})</td>
</tr>
<tr>
<td>(^{40})Ca</td>
<td>165</td>
</tr>
<tr>
<td>(^{56})Fe</td>
<td>45</td>
</tr>
<tr>
<td>(^{59})Co</td>
<td>(1.93 \times 10^7)</td>
</tr>
<tr>
<td>(^{65})Zn</td>
<td>244</td>
</tr>
<tr>
<td>(^{85})Rb</td>
<td>18.8</td>
</tr>
<tr>
<td>(^{88})Sr</td>
<td>(1.1 \times 10^{17})</td>
</tr>
<tr>
<td>(^{99m})Tc</td>
<td>0.25</td>
</tr>
<tr>
<td>(^{123})I</td>
<td>0.54</td>
</tr>
<tr>
<td>(^{127})I</td>
<td>8</td>
</tr>
<tr>
<td>(^{133})Cs</td>
<td>(1.1 \times 10^{10})</td>
</tr>
<tr>
<td>(^{137})Ba</td>
<td>12.8</td>
</tr>
<tr>
<td>(^{186})Au</td>
<td>2.7</td>
</tr>
<tr>
<td>(^{210})Po</td>
<td>138</td>
</tr>
<tr>
<td>(^{228})Ra</td>
<td>(5.8 \times 10^{13})</td>
</tr>
<tr>
<td>(^{226})U</td>
<td>2.6 \times 10^{14}</td>
</tr>
<tr>
<td>(^{239})Pu</td>
<td>(8.8 \times 10^{14})</td>
</tr>
</tbody>
</table>

**Table 12**: The relationship between radiological and biological half-life (Tuszynski and Dixon, 2001)
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 13).

<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 cataracts</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 13: 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 to years to appear (Table 13).

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 effects 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 in to 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 13) 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 14).

<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 14: 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 15). 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 15: 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 CT Scans. Cohen\(^{10}\) (1991) provides a snapshot of the typical exposures that can be expected through various radiological diagnostic procedures (Table 16).

<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></td>
<td>Infant: 0.8 mSv</td>
</tr>
<tr>
<td>Mammography</td>
<td>0.7 mSv</td>
</tr>
</tbody>
</table>

Table 16: Radiological procedures and their effective doses (Cohen, 1991)

\(^{10}\) 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.

ALARA

The principle of optimisation can be expressed by the acronym ALARA – As Low As Reasonably Achievable.

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

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.
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 14). 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.

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

The penetrating properties of the ionising radiation (Figure 15) are dependent on the:
- type of radiation;
- activity of the source; and
- dose rate.

**Note**

Shielding is not considered a primary means of reducing exposure to alpha particles given that alpha particles are “stopped” at the moment of contact with any surface.
Figure 15: Penetrating properties of particulate ionising radiation and electromagnetic radiation

**Alpha Radiation**

As previously determined alpha particles are easily absorbed and are not considered an external hazard to the body. They will quickly ionise in air and therefore shielding is normally not required. A thin sheet of paper is usually 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.

**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:

\[ I = I_0/2^n \]

\( I = \) shielded dose rate \( I_0 = \) unshielded dose rate \( n = \) number of half-value layers

Tenth-Value Layer

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

Tenth-value layer can be calculated from the following equation:

\[ I = I_0/10^n \]

\( I = \) shielded dose rate \( I_0 = \) unshielded dose rate \( n = \) number of tenth-value layers

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

Application

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

Jones (2003) provides examples of radiation sources emitting gamma rays and their corresponding shielding requirements (Table 17).

<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>⁶⁰Co</td>
<td>1.25 MeV</td>
<td>5.26 years</td>
<td>11</td>
<td>33.9</td>
</tr>
<tr>
<td>²²⁶Ra</td>
<td>1.03 MeV</td>
<td>1.626 years</td>
<td>16</td>
<td>28.9</td>
</tr>
<tr>
<td>¹³⁷Cs</td>
<td>662 keV</td>
<td>30 years</td>
<td>6.5</td>
<td>18.5</td>
</tr>
<tr>
<td>¹⁹²Ir</td>
<td>360 keV</td>
<td>74.2 days</td>
<td>3.1</td>
<td>7.1</td>
</tr>
<tr>
<td>²²²Rn</td>
<td>1.03 keV</td>
<td>3.83 days</td>
<td>1.6</td>
<td>2.9</td>
</tr>
<tr>
<td>¹⁹⁸Au</td>
<td>412 keV</td>
<td>2.7 days</td>
<td>3.3</td>
<td>8.9</td>
</tr>
<tr>
<td>¹²⁵I</td>
<td>28 keV</td>
<td>59 days</td>
<td>0.025</td>
<td>0.38</td>
</tr>
<tr>
<td>¹⁰⁢³Pd</td>
<td>22 keV</td>
<td>17 days</td>
<td>0.013</td>
<td>0.21</td>
</tr>
<tr>
<td>¹⁶⁹Yb</td>
<td>93 keV</td>
<td>32 days</td>
<td>1.6</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Table 17: HVL and TVL shielding requirements for radiation sources emitting gamma rays (Jones, 2003)
Summary of Shielding

Table 18 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 18: Summary of radiation properties and shielding requirements

6.3 CONTROLS TO PREVENT INTERNAL EXPOSURE

The principles of internal protection/contamination control 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 can not 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.
6.4 EFFECTIVE CONTROL

6.4.1 Case Study

Background

In February 2009 after months of planning a large radioactive source of $^{60}\text{Co}$ (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 $^{60}\text{Co}$ 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 $^{60}\text{Co}$ from the containment vessel; and
- placing the $^{60}\text{Co}$ in a shielded transport vessel.

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

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

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

<table>
<thead>
<tr>
<th>Effective Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>The safe use and effective control of radiation requires:</td>
</tr>
<tr>
<td>• Knowledge</td>
</tr>
<tr>
<td>A thorough understanding of the radiological material been used.</td>
</tr>
<tr>
<td>• Skills and experience</td>
</tr>
<tr>
<td>Previous experience utilising safe working controls with radiological materials.</td>
</tr>
<tr>
<td>• Work practices.</td>
</tr>
<tr>
<td>Continuing use of safe work practices.</td>
</tr>
</tbody>
</table>

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 ARPANSA web site</td>
<td></td>
</tr>
<tr>
<td>AS 2243.4 Safety in laboratories. Part 4. Ionising radiations (Standards Association of Australia, 1998)</td>
<td>Instructions:</td>
</tr>
<tr>
<td></td>
<td>1. Log-on to the University Library Supersearch. Link: <a href="http://www.library.unimelb.edu.au/">http://www.library.unimelb.edu.au/</a></td>
</tr>
<tr>
<td></td>
<td>2. Log-on to Supersearch and access the Standards through SAI Global – Australian Standards.</td>
</tr>
</tbody>
</table>

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>.


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 16). The radiation tri-foil is an internationally recognised symbol for ionising radiation. The tri-foil is black on a yellow background.

Figure 16: Ionising radiation tri-foil symbol

Figure 17: 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.

Supplementary Ionising Radiation Warning Symbol

In 2007 the International Standardization Organization (ISO) and IAEA published a supplementary ionising radiation warning symbol (Figure 17).

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).
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 “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 2000 (Victorian Government, 2000) 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 16).

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 19).

<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 (which ever 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 19: 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 18).

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 18: Code of practice security of radioactive sources (ARPANSA, 2007)

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\textsuperscript{11}).

\textsuperscript{11} 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 information on:</td>
<td><a href="http://safety.unimelb.edu.au/topics/chemical/">http://safety.unimelb.edu.au/topics/chemical/</a></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>
</tr>
<tr>
<td>• Storage and Handling</td>
<td></td>
</tr>
<tr>
<td>• Poisons Control Plan</td>
<td></td>
</tr>
<tr>
<td>• Government and External Party Publications</td>
<td></td>
</tr>
<tr>
<td>Melbourne Policy Library</td>
<td></td>
</tr>
<tr>
<td>• Chemical Risk Management (UOM 320)</td>
<td><a href="http://policy.unimelb.edu.au/UOM0320">http://policy.unimelb.edu.au/UOM0320</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 Supersearch. A UoM user name and password is required.</td>
<td></td>
</tr>
<tr>
<td>Code of practice security of radioactive sources (ARPANSA, 2007)</td>
<td></td>
</tr>
</tbody>
</table>

7.4 REFERENCES


© The University of Melbourne – Uncontrolled when printed.
8 MONITORING EQUIPMENT

8.1 RADIATION BADGES

The UoM Radiation Management Plan requires, where applicable, that individuals working with radiation sources have personal monitoring to identify their level of exposure over a regular time frame. For this purpose radiation badges are used for personal dosimetry.

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

Typically radiation badges are intended to minimise both deterministic and stochastic effects.

8.1.1 Thermoluminescent Dosimetry badge

A thermoluminescent dosimetry (TLD) badge contains a radioactive sensitive material, such as film, inserted into a small plastic housing. It is worn on a person’s clothing and records the accumulated ionising radiation exposure of the person over a period of time.

![Figure 19: Examples of TLD badges](image)

**Thermoluminescent Dosimetry Badge**

TLD badges (Figure 19) are used extensively at the UoM. It is expected that personnel working with radiation sources are issued with a personal TLD badge. A TLD badge is used only by the person that it is issued to and cannot be shared. If a TLD badge is lost or damaged it should be reported to the supervisor as soon as possible.

The red TLD badge is for monitoring beta and gamma radiation.

The blue TLD badge is for monitoring neutron radiation.

**TLD Badge Requirements**

The routine procedure for TLD badges includes:
- tested quarterly;
- results made available to individuals;
- results stored on file; and
- results made available to the department on request.

A TLD badge 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 badge is the delay in receiving the results. As the TLD badge is tested on a quarterly basis it means that the dose is not known for three months. Therefore it is essential to ensure good working practices are in place at all times.

**Note**

TLD badges are unsuitable for monitoring alpha particles and low energy beta particles.
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 badge with additional benefits that include:
• the results are in real time with no delay in receiving results;
• 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 preset alarm levels.

Currently the UoM uses a limited number of real time neutron/gamma monitors and beta/gamma monitors (Figure 20). The monitor on left in Figure 20 measures neutron/gamma radiation and the monitor on the right measures beta/gamma radiation.

![Figure 20: Examples of real time dose monitors](image)

8.2 Meters

Radiation meters fall into two main groups (Figure 21):
• survey meters; and
• contamination meters.

![Figure 21: Examples of survey and contamination meters](image)

8.2.1 Survey Meters

Survey meters, also referred to as dose rate meters, measure external radiation in units of equivalent dose rate. This means that the measurements are in sievert (Sv)/h. They provide a measurement of the rate of radiation received by a person.

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. Things to consider include:

- the type of radiation measured (beta, alpha, gamma etc);
- the energy levels measured;
- the type and intended use (eg. you cannot use a contamination meter to do a survey); and
- the level of efficiency when measuring radiation (see Table 20).

Meters are not 100% accurate at measuring ionising radiation. For example Table 20 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>Emax2π (keV)</th>
<th>2π Effic %</th>
<th>Sensitivity cps/Bq/cm²</th>
<th>MDL Bq/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>¹⁴C</td>
<td>156</td>
<td>3</td>
<td>0.25</td>
<td>9.0</td>
</tr>
<tr>
<td>³⁵S</td>
<td>167</td>
<td>8</td>
<td>0.65</td>
<td>3.7</td>
</tr>
<tr>
<td>¹⁴⁷Pm</td>
<td>224</td>
<td>15</td>
<td>1.25</td>
<td>2.0</td>
</tr>
<tr>
<td>⁹⁹Tc</td>
<td>290</td>
<td>20</td>
<td>1.75</td>
<td>1.5</td>
</tr>
<tr>
<td>⁹⁰Sr + ⁹⁰Y</td>
<td>580 + 2280</td>
<td>50</td>
<td>8.50</td>
<td>0.3</td>
</tr>
<tr>
<td>³⁶Cl</td>
<td>714</td>
<td>45</td>
<td>3.50</td>
<td>0.7</td>
</tr>
<tr>
<td>²¹⁰Pb</td>
<td>1160</td>
<td>50</td>
<td>4.00</td>
<td>0.6</td>
</tr>
<tr>
<td>³²P</td>
<td>1710</td>
<td>70</td>
<td>5.50</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 20: 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 21). 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 µSv/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 to energy</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>Wide range of operation: -10ºC to +50ºC 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 21: Operational considerations when purchasing a radiation meter
8.2.5 Operational and Calibration Requirements

The general operational and calibration requirements for most survey and contamination meters are similar with only minor differences (Table 22).

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 &quot;battery check&quot; 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 &quot;battery check&quot; 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 22: Operational and calibration requirements of survey and contamination meters
8.2.6 Assessment of a Contamination Meter

Although a contamination meter does not require annual calibration 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 22).

2. At regular scheduled intervals (eg 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 23). 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 23 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 22:** Placement of a radioactive source with a known activity at a predetermined distance from the contamination meter

**Figure 23:** Contamination meter chart showing possible outcomes of meter results over a period of time
8.3 Radiation Survey

In Section 5.6 it was determined that ionising radiation exposure could be external or internal. External exposure would most likely occur from radioactive particulates or electromagnetic radiation in the air (environment around us). Whereas internal contamination requires taking the radioactive particulates into the body through inhalation, ingestion 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. Ionising radiations (Standards Association of Australia, 1998).

In summary, radiation surveys are undertaken to ensure that:
- radioactive exposure levels are as low as reasonably possible; and
- radioactive contamination and/or 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 for elevated dose rates or increased dose rates from one survey to the next. Where elevated levels are detected action can 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 removable 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 completed 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 a contamination meter in an area of known low radiation background. If there were surface contaminants these would be removed with 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. At the UoM external and surface contamination radiation surveys are more common than contamination radiation surveys (Table 23).

Some radiation surveys may be a legal requirement. For example a requirement of the UoM Radiation Management Licence includes annually wipe testing soil moisture/density gauges\(^\text{12}\).

<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>
<tr>
<td>Radiation store</td>
<td>External survey and Surface Contamination</td>
<td>Annually</td>
<td>The surveys ensure:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• the continued low level of expected radiation; and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• radioactive contaminants remain intact and are not carried outside the store.</td>
</tr>
</tbody>
</table>

Table 23: Common radiation survey requirements for the UoM

8.4 DOCUMENTATION

Results should be documented and retained for:
- calibration results and certificates of survey monitors;
- assessment results of contamination monitors; and
- survey results of local areas.

8.5 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health &amp; Safety Common Services 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 Supersearch. A UoM user name and password is required.</td>
<td>Instructions:</td>
</tr>
<tr>
<td></td>
<td>1. Access the University Library Supersearch. Link: <a href="http://www.library.unimelb.edu.au/">http://www.library.unimelb.edu.au/</a></td>
</tr>
<tr>
<td></td>
<td>2. Log-on to Supersearch and access the Standards through SAI Global – Australian Standards.</td>
</tr>
</tbody>
</table>

\(^{12}\) 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).
8.6 REFERENCES


9 INCIDENTS AND EMERGENCIES

9.1 DEFINITION OF A RADIOLOGICAL INCIDENT

The Department of Health (Department of Human Services, 2007) define radiological incidents as:

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

A condition of the UoM Radiation Management Licence is that “radiological incidents” are reported to Health Department in accordance with Radiation incidents reporting requirements (Department of Human Services, 2007). Refer to Table 2 under Schedule 1.

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 contain 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:

- raising the alarm;
- getting help (call emergency services, UoM emergency phone);
- making the area safe (if safe to do so); and
- evacuating the area to a predetermined evacuation point.

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 RSA for assistance and advice. The UoM RSA shall notify the Health Department if the radiological incident falls under the definition of a “radiological incident”.

The UoM procedure Incident Reporting and Investigation – EHS Requirements (UOM 364) 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 the assistance of the DRSO. The DRSO shall contact the UoM RSA to:

- advise of the incident; and
- seek additional support if required.

### 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.

There should also be a process for ad hoc reviews. These would occur 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; and
- first aid requirements.

Where the incident can be managed by the local area, the DRSO (as a minimum) should be notified. From all incidents there are lessons that can be learned and these may be informative for other areas that undertake similar activities.

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 9.2.

---

**UoM Procedures**

Emergency procedures should take into account the UoM procedure *Emergency Preparedness & Response (UOM 356).*

First aid procedures should take into account the UoM procedure *First Aid OHS Requirements (UOM 358).*
9.5 SOURCING FURTHER INFORMATION

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melbourne Policy Library:</td>
<td></td>
</tr>
<tr>
<td>• Incident Reporting and Investigation – EHS Requirements (UOM 364)</td>
<td><a href="http://policy.unimelb.edu.au/UOM0364">http://policy.unimelb.edu.au/UOM0364</a></td>
</tr>
<tr>
<td>Melbourne Policy Library:</td>
<td></td>
</tr>
<tr>
<td>• First Aid – OHS Requirements (UOM 358)</td>
<td><a href="http://policy.unimelb.edu.au/UOM0358">http://policy.unimelb.edu.au/UOM0358</a></td>
</tr>
<tr>
<td>Melbourne Policy Library:</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>• Safety Bulletin 05-09: First Aid &amp; Emergency Response</td>
<td><a href="http://safety.unimelb.edu.au/topics/firstaid/">http://safety.unimelb.edu.au/topics/firstaid/</a></td>
</tr>
<tr>
<td>• Basic First Aid Kit Contents</td>
<td></td>
</tr>
<tr>
<td>• First Aid – OHS Requirements (UOM 358)</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>The UoM Emergency &amp; Incidents web page</td>
<td></td>
</tr>
<tr>
<td>OHS Common Services 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>

9.6 REFERENCES


Local Area Emergency Response – Practical Considerations

The local area should have documented emergency procedures. Personnel in the local area should be familiar with these procedures.

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

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

Take the time to let other people in the area know what has happened, such as signs (Figure 24).

Restrict access to the area.

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

10.1 METHODS OF RADIOACTIVE WASTE MANAGEMENT

The disposal method of radioactive waste is mainly determined by the radiological activity of that waste. The three disposal methods (Table 24) are:

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

10.1.1 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.

10.1.2 Delay and Decay

Short-lived radiation sources can be stored and allowed to decay into non-radioactive waste. This waste can then be disposed of through the appropriate waste stream.

10.1.3 Concentration and Containment

Radiation sources with long half-lives require long term storage in a suitably built area. These radioactive wastes are managed by OHS Common Services.

10.2 UNIVERSITY REQUIREMENTS

The UoM has adopted the above methods of radioactive waste management when disposing of radioactive wastes.

---

<table>
<thead>
<tr>
<th>Disposal Method</th>
<th>Examples</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilution and dispersion</td>
<td>$^{14}$C</td>
<td>When diluted to non-radioactive levels $^{14}$C is disposed of through the UoM EPA waste contractor.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$^{3}$H When diluted to non-radioactive levels $^{3}$H can be emptied down the sink.</td>
</tr>
<tr>
<td>Delay and decay</td>
<td>$^{32}$P and $^{33}$P</td>
<td>$^{32}$P and $^{33}$P can be stored at the local area until they have decayed to a non-radiological level. Length of decay will depend on both the half-life and the activity.</td>
</tr>
<tr>
<td>Concentration and containment</td>
<td>$^{137}$Cs</td>
<td>$^{137}$Cs has a half-life of 30 years and is stored in an appropriately built location.</td>
</tr>
</tbody>
</table>

Table 24: Disposal methods of radioactive waste management at the UoM

Note

Ensure that dilution and dispersion does not introduce other hazards (such as chemicals) into the environment.
10.2.1 UoM Hazardous Waste Collection

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.

Local areas can access the hazardous waste collection service in a number of ways. For example by:

- emailing OHS Common Services waste collection email address (48 hours prior to the scheduled collection);
- contacting the DRSO; or
- contacting the department manager.

10.2.2 Containment of Waste

Radioactive wastes that require concentration and containment are managed by OHS Common Services. 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 RSA who will make arrangements for the removal of the radioactive waste.

10.3 Sourcing Further Information

<table>
<thead>
<tr>
<th>Description of Information</th>
<th>Where to Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>OHS Common Services radiation advice email</td>
<td><a href="mailto:radiation-info@unimelb.edu.au">radiation-info@unimelb.edu.au</a></td>
</tr>
<tr>
<td>OHS Common Services 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>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>The UoM Hazardous Waste Collection web page that provides information and advice on hazardous waste collection at the university</td>
<td><a href="http://safety.unimelb.edu.au/support/waste/">http://safety.unimelb.edu.au/support/waste/</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: dilution and dispersion; and delay and decay.</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>
</tbody>
</table>

10.4 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 as soon as possible after 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 as soon as practicable after 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;
• personal TLD badge and associated procedures;
• 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. Where radioactive activities commence prior to training, personnel should work under direct supervision.

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 OHS Common Services. 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 OHS Common Services. The purpose of the training is to provide information on ionising radiation theory and requirements. The emphasis is on working safely with ionising radiation 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 – DRSO

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.

Training can be arranged on-line through Themis or by contacting OHS Common Services.

General training requirements are outlined in the UoM procedure *EHS Training (UOM 311)*.

### 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.

The UoM uses two variable or three variable risk assessment methodologies when assigning risk ratings to identified hazards. A hazard-specific risk assessment template for ionising radiation has not been developed. Nevertheless the following UoM generic risk assessment templates can readily be adopted for assessing ionising radiation. These include the:

- Task Risk Analysis 2 Variable; and
- Task Risk Analysis 3 Variable.

Risk assessment requirements are outlined in the UoM procedure *EHS Risk Management (UOM 306)*.

---

**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 the risks to as low a level as practicable. It is listed below in order of effectiveness.

a. Elimination:
   Remove the hazard. eg eliminating a requirement to carry out the task, use a piece of equipment or utilise a chemical.

b. Substitution:
   Replace the material, plant or work practice with a less hazardous one. eg. replacing a hazardous chemical with a less hazardous one.

c. Engineering Controls:
   Engineering the solution to minimise risk is highly desirable as the process reduces the reliance on human behaviour to effect long lasting positive change. There are a number of aspects to engineering controls.
   - One may 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.
   - One may isolate a hazard by physically guarding the hazard, enclosing the hazard thus preventing human contact, may lock a process/equipment thus preventing access by any unauthorised personnel, may remove the hazard by engineering means such as ventilation.

d. Administration Controls:
   Administration controls are the procedural aspects of managing hazards, such as planned and preventative maintenance programs, standard operating procedures, lock out/tag out 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. It involves staff wearing appropriate PPE such as steel mesh gloves, safety shoes, aprons, goggles etc, to isolate the person from the hazard. Any breakdown of the system immediately exposes the worker to the hazard. This control method is not highly effective because it relies totally on human behaviour. PPE often forms part of the ‘short term’ controls methodology.

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.

UoM procedure EHS Risk Management (UOM 306) outlines the following requirements when developing an SOP:
- Supervisors/managers, in consultation with personnel, may 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 may use the University SOP template for SOPs or OHS work instructions.

Incidents and Emergencies

It is important that standard operating procedures take into account emergency requirements of possible radiological incidents and emergencies.
11.4 PURCHASING

Divisions and departments have pre-existing arrangements in place to enable the ongoing purchase of radiation sources. Where new radiation sources are purchased there will be additional requirements. These include:

- completing a Health & Safety Pre-Purchase Checklist; and
- notifying the DRSO and the UoM RSA.

This section discusses the requirements associated with purchasing new radiation sources.

11.4.1 Health & 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 & Safety Pre-Purchase Checklist has been completed prior to the authorising the purchase.

Pre-purchase requirements are outlined in the UoM procedure Purchasing – EHS Requirements (UOM 327).

11.4.2 Notification

Radiation sources can only be purchased where the supplier is provided with a Radiation Management Licence Number. The UoM Radiation Management Licence number is only available on request to the UoM RSA and under strict criteria for its use.

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 RSA.

Prior to purchase the UoM RSA must be notified so that they can:

- add the radiation source to the UoM Radiation Management Licence (refer to Section 2.2.3); and
- provide guidance where required.

Purchase of New Radiological Materials

It is preferable that supervisors/managers considering the purchase of new radiation sources contact the UoM RSA as soon as practicable. New purchases can have complex considerations and requirements that require careful preplanning and arrangements.
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 doses of 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.

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 (exempt packages);
- 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 25).

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.

![Image of labeling types](image)

**Figure 25: Radioactive packaging labelling during transport**

### Placarding

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


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.

**Figure 26: Placard requirements for a Class 7 Dangerous Good**

### Exempt Packaging

Exempt 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.

![Image of exempt packaging label](image)

**Figure 27: Transport label required on the outside surface of an exempt package**

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 27). Compare these labelling requirements with the labelling requirements of radiation sources that are not exempt (Figure 25).
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 RSA 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><strong>Induction and Training</strong></td>
<td></td>
</tr>
<tr>
<td>Melbourne Policy Library:</td>
<td></td>
</tr>
<tr>
<td>• EHS Training (UOM 311)</td>
<td><a href="http://policy.unimelb.edu.au/UOM0311">http://policy.unimelb.edu.au/UOM0311</a></td>
</tr>
</tbody>
</table>

| **Risk Assessment**                                  |                                                                                |
| Melbourne Policy Library:                           |                                                                                |
| • EHS Risk Management (UOM 306)                      | http://policy.unimelb.edu.au/UOM0306                                           |
| including 2-variable and 3-variable templates       |                                                                                |
| UoM risk assessment templates                       |                                                                                |

| **Standard Operating Procedures**                    |                                                                                |
| UoM SOP template for developing and SOP or EHS work  | http://safety.unimelb.edu.au/docs/SOPTemplate.doc                             |
| instructions.                                        |                                                                                |
| Whilst the template has been developed for activities|                                                                                |
| related to equipment/machinery it can be readily    |                                                                                |
| adapted for activities using ionising radiation     |                                                                                |
| materials.                                           |                                                                                |

| **Purchasing**                                       |                                                                                |
| Melbourne Policy Library:                           |                                                                                |
| • Purchasing – EHS Requirements (UOM 327)           | http://policy.unimelb.edu.au/UOM0327                                           |
| Assessment                                           |                                                                                |

| **Transport**                                        |                                                                                |
| radioactive material* (ARPANSA, 2008a) adopts the   |                                                                                |
| International Atomic Energy Agency’s *Regulations    |                                                                                |
| for the safe transport of radioactive material 2005  |                                                                                |
| (IEAE, 2005). It establishes uniform requirements    |                                                                                |
| for the transport of radiation source in Australia.  |                                                                                |
| The *Safety guide for the safe transport of radioactive material* (ARPANSA, 2008b) is additional guidance that can be used in conjunction with the *Code of practice for the safe transport of radioactive material* (ARPANSA, 2008a). | http://www.arpansa.gov.au/pubs/rps/rps2_1.pdf |
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
- undertakes ionising radiation activities in a manner that is without risks to health and safety.

The certification process is undertaken by members of the Electromagnetic Radiation Safety Committee. Records of certification are maintained centrally by the OHS Common Services. 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 (Figure 28).

Figure 28: UoM laboratory certification sticker

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 OHS Common Services, 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><a href="http://safety.unimelb.edu.au/topics/radiation/certification/">http://safety.unimelb.edu.au/topics/radiation/certification/</a></td>
</tr>
<tr>
<td>- Laboratory Certification Inspection Checklist – Ionising Radiation Laboratory</td>
<td></td>
</tr>
<tr>
<td>- Ionising Radiation Laboratory Inspection Preparation</td>
<td></td>
</tr>
<tr>
<td>Common Services, Occupational Health and Safety advice, information and guidance on ionising radiation practices within the UoM (Figure 29)</td>
<td><a href="http://safety.unimelb.edu.au/topics/radiation/">http://safety.unimelb.edu.au/topics/radiation/</a></td>
</tr>
<tr>
<td>The web site is under currently under construction.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 29: A screen shot of the UoM radiation web page
13 LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALARA</td>
<td>As Low As Reasonably Achievable</td>
</tr>
<tr>
<td>ANSTO</td>
<td>Australian Nuclear Science and Technology Organisation</td>
</tr>
<tr>
<td>ARPANSA</td>
<td>Australian Radiation Protection and Nuclear Safety Association</td>
</tr>
<tr>
<td>AS</td>
<td>Australian Standard</td>
</tr>
<tr>
<td>CPM</td>
<td>Counts Per Minute</td>
</tr>
<tr>
<td>CPS</td>
<td>Counts Per Second</td>
</tr>
<tr>
<td>DRSO</td>
<td>Departmental Radiation Safety Officer</td>
</tr>
<tr>
<td>DPS</td>
<td>Disintegrations Per Second</td>
</tr>
<tr>
<td>EHS</td>
<td>Environment Health and Safety</td>
</tr>
<tr>
<td>EMR</td>
<td>Electromagnetic Radiation</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Society</td>
</tr>
<tr>
<td>ERSC</td>
<td>Electromagnetic Radiation Safety Committee</td>
</tr>
<tr>
<td>HVL</td>
<td>Half-Value Layer</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
</tr>
<tr>
<td>ICRP</td>
<td>International Commission of Radiological Protection</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>LLE</td>
<td>Loss of Life Expectancy</td>
</tr>
<tr>
<td>MSDS</td>
<td>Material Safety Data Sheet</td>
</tr>
<tr>
<td>NHMRC</td>
<td>National Health and Medical Research Council</td>
</tr>
<tr>
<td>OHSC</td>
<td>Occupational Health and Safety Committee</td>
</tr>
<tr>
<td>PPE</td>
<td>Personal Protective Equipment</td>
</tr>
<tr>
<td>RSA</td>
<td>Radiation Safety Officer</td>
</tr>
<tr>
<td>SI</td>
<td>(Système Internationale) International System of Units</td>
</tr>
<tr>
<td>SOP</td>
<td>Standard Operating Procedure</td>
</tr>
<tr>
<td>TLD</td>
<td>Thermoluminescent Dosimetry</td>
</tr>
<tr>
<td>TVL</td>
<td>Tenth-Value Layer</td>
</tr>
<tr>
<td>UoM</td>
<td>University of Melbourne</td>
</tr>
<tr>
<td>UoM RSA</td>
<td>University of Melbourne Radiation Safety Officer</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. Ionising 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</th>
<th>Main gamma ray energy</th>
<th>Gamma ray constant</th>
<th>Most restrictive occupational inhalation ALI</th>
<th>Occupational DAC (Note 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MeV (% abundance)</td>
<td>MeV (% abundance) †</td>
<td>µSv/h §</td>
<td></td>
<td>Bq/m³</td>
</tr>
<tr>
<td>H-3 (gas)</td>
<td>4</td>
<td>12.3y</td>
<td>10d</td>
<td>0.018</td>
<td>---</td>
<td>---</td>
<td>1.1×10⁻⁷</td>
<td>4.6×10⁻⁴</td>
</tr>
<tr>
<td>H-3 (water Vapour)</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.7×10⁻⁷</td>
<td>3.2×10⁻⁴</td>
</tr>
<tr>
<td>H-3 (organically bound)</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.9×10⁻⁴</td>
<td>2.0×10⁻⁴</td>
</tr>
<tr>
<td>C-11</td>
<td>4</td>
<td></td>
<td></td>
<td>0.96 (98%) (positrons)</td>
<td>0.511 (200%)</td>
<td>194</td>
<td>1.7×10⁻⁷</td>
<td>9.1×10⁻⁶</td>
</tr>
<tr>
<td>C-11 (vapour)</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.1×10⁻⁶</td>
<td>3.8×10⁻⁶</td>
</tr>
<tr>
<td>C-11 monoxide</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.3×10⁻⁶</td>
<td>2.6×10⁻⁶</td>
</tr>
<tr>
<td>C-11 dioxide</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>C-14</td>
<td>4</td>
<td></td>
<td></td>
<td>5730y</td>
<td>0.156 (100%)</td>
<td>---</td>
<td>3.4×10⁻⁷</td>
<td>1×10⁻⁷</td>
</tr>
<tr>
<td>C-14 (vapour)</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.5×10⁻⁷</td>
<td>3.8×10⁻⁶</td>
</tr>
<tr>
<td>C-14 monoxide</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.1×10⁻⁶</td>
<td>1.4×10⁻⁴</td>
</tr>
<tr>
<td>C-14 dioxide</td>
<td>4</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-13</td>
<td>3b</td>
<td>9.97m</td>
<td></td>
<td>1.190 (100%)</td>
<td>0.511 (200%)</td>
<td>194</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>C-15</td>
<td>2.04m</td>
<td>1.7 (100%) postions</td>
<td>0.511 (200%)</td>
<td>194</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
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<td>F-18</td>
<td>4</td>
<td>1.83h</td>
<td>6h</td>
<td>0.635 (97%) positrons</td>
<td>0.511 (193%)</td>
<td>188</td>
<td>2.2×10⁻⁶</td>
<td>9.0×10⁻⁴</td>
</tr>
<tr>
<td>Na-22</td>
<td>3b</td>
<td>2.6y</td>
<td>11d</td>
<td>0.540 (89%) positrons</td>
<td>0.511 (180%) 1.270 (100%)</td>
<td>360</td>
<td>1.0×10⁻⁷</td>
<td>4.2×10⁻³</td>
</tr>
<tr>
<td>Na24</td>
<td>3b</td>
<td>15h</td>
<td></td>
<td>1.390 (99.9%)</td>
<td>1.37 (100%) 2.750 (100%)</td>
<td>520</td>
<td>3.8×10⁻⁷</td>
<td>1.6×10⁻⁴</td>
</tr>
<tr>
<td>P-32</td>
<td>3a</td>
<td>14.3d</td>
<td>257d</td>
<td>1.700 (100%)</td>
<td>---</td>
<td>---</td>
<td>69×10⁻⁷</td>
<td>2.8×10⁻⁷</td>
</tr>
<tr>
<td>P-33</td>
<td>3b</td>
<td>25.4d</td>
<td>257d</td>
<td>0.249 (100%)</td>
<td>---</td>
<td>---</td>
<td>15×10⁻⁷</td>
<td>6.4×10⁻⁴</td>
</tr>
<tr>
<td>S-35 (inorganic)</td>
<td>3b</td>
<td>87d</td>
<td>90d</td>
<td>0.167 (100%)</td>
<td>---</td>
<td>---</td>
<td>1.8×10⁻⁷</td>
<td>7.6×10⁻⁷</td>
</tr>
<tr>
<td>S-35 (org. bound gas/vapour)</td>
<td>3b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.7×10⁻⁷</td>
<td>6.9×10⁻⁴</td>
</tr>
<tr>
<td>K-42</td>
<td>4</td>
<td>12.4h</td>
<td></td>
<td>3.52 (82%) 2.0 (16%)</td>
<td>1.520 (18%)</td>
<td>39</td>
<td>1.0×10⁻⁷</td>
<td>4.2×10⁻⁴</td>
</tr>
<tr>
<td>Ca-45</td>
<td>3a</td>
<td>163d</td>
<td>45y</td>
<td>0.260 (99.9%)</td>
<td>---</td>
<td>---</td>
<td>8.7×10⁻⁷</td>
<td>3.6×10⁻⁴</td>
</tr>
<tr>
<td>Ca-47</td>
<td>3a</td>
<td>4.54d</td>
<td></td>
<td>0.690 (82%) 1.990 (18%)</td>
<td>1.300 (75%)</td>
<td>160</td>
<td>9.5×10⁻⁵</td>
<td>4.0×10⁻⁴</td>
</tr>
<tr>
<td>Sc-47</td>
<td>3b</td>
<td>3.351d</td>
<td></td>
<td>0.440 (68%) 0.601 (32%)</td>
<td>0.159 (68%)</td>
<td>22.63</td>
<td>2.7×10⁻⁷</td>
<td>1.1×10⁻⁴</td>
</tr>
<tr>
<td>Cr-51</td>
<td>4</td>
<td>27.7d</td>
<td>616d</td>
<td>0.470 (43%) 0.270 (46%)</td>
<td>1.100 (57%) 1.280 (43%)</td>
<td>180</td>
<td>6.3×10⁻⁸</td>
<td>2.6×10⁻³</td>
</tr>
<tr>
<td>Fe-55</td>
<td>3b</td>
<td>2.7y</td>
<td>2000d</td>
<td>0.005 (16%)</td>
<td></td>
<td></td>
<td>2.2×10⁻⁷</td>
<td>9.1×10⁻⁴</td>
</tr>
<tr>
<td>Fe-59</td>
<td>3a</td>
<td>45d</td>
<td>700d</td>
<td>0.470 (43%) 0.270 (46%)</td>
<td></td>
<td></td>
<td>1.100 (57%) 1.280 (43%)</td>
<td>6.3×10⁻⁸</td>
</tr>
<tr>
<td>Nuclide</td>
<td>Radio-toxicity group</td>
<td>Half-life</td>
<td>Biological half-life</td>
<td>Max. energy of main beta rays MeV (% abundance)</td>
<td>Main gamma ray energy MeV (% abundance)</td>
<td>Gamma ray constant µSv/h $\dagger$</td>
<td>Most restrictive occupational inhalation ALI Bq</td>
<td>Occupational DAC (Note 1) Bq/m³</td>
</tr>
<tr>
<td>----------</td>
<td>----------------------</td>
<td>----------</td>
<td>---------------------</td>
<td>-----------------------------------------------</td>
<td>----------------------------------------</td>
<td>----------------------------------</td>
<td>--------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Co-57</td>
<td>3b</td>
<td>271d</td>
<td>9.5d</td>
<td>---</td>
<td>0.122 (86%)</td>
<td>41</td>
<td>3.3×10⁷</td>
<td>1.4×10⁴</td>
</tr>
<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%)</td>
<td>170</td>
<td>1.2×10⁷</td>
<td>4.9×10³</td>
</tr>
<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%)</td>
<td>370</td>
<td>1.2×10⁷</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)</td>
<td>0.511 (35.7%)</td>
<td>36</td>
<td>1.3×10⁸</td>
<td>5.6×10⁴</td>
</tr>
<tr>
<td>Cu-67</td>
<td>3b</td>
<td>61.7h</td>
<td>3.78d</td>
<td>0.390 (56%)</td>
<td>0.090 (17%)</td>
<td>24</td>
<td>3.4×10⁷</td>
<td>1.4×10⁷</td>
</tr>
<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>
</tr>
<tr>
<td>Ga-67</td>
<td>3b</td>
<td>3.26d</td>
<td></td>
<td>---</td>
<td>0.093 (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>
<td>1.5×10⁴</td>
<td>1.0×10⁴</td>
</tr>
<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>2.5×10⁴</td>
<td>1.1×10⁴</td>
</tr>
<tr>
<td>Se-75</td>
<td>3b</td>
<td>119.8d</td>
<td></td>
<td>---</td>
<td>0.265 (59.8%)</td>
<td>230</td>
<td>1.2×10⁷</td>
<td>4.9×10⁷</td>
</tr>
<tr>
<td>Br-82</td>
<td>3b</td>
<td>1.47d</td>
<td></td>
<td>0.444 (98%)</td>
<td>0.62 (43%)</td>
<td>440</td>
<td>2.3×10⁷</td>
<td>9.5×10⁵</td>
</tr>
<tr>
<td>Rb-86</td>
<td>3b</td>
<td>18.7d</td>
<td>45d</td>
<td>0.697 (8.8%) 1.774 (91.2%)</td>
<td>---</td>
<td>15</td>
<td>1.5×10⁷</td>
<td>6.4×10³</td>
</tr>
<tr>
<td>Sr-89</td>
<td>3a</td>
<td>50.5d</td>
<td>1.8 x 10⁴d</td>
<td>1.49 (100%)</td>
<td>---</td>
<td>---</td>
<td>3.6×10⁷</td>
<td>1.5×10⁷</td>
</tr>
<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>4.9×10⁶</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>
<td>1.8×10⁷</td>
<td>7.6×10³</td>
</tr>
<tr>
<td>Tc-99m</td>
<td>4</td>
<td>6.0h</td>
<td>20d</td>
<td>0.14 (89%)</td>
<td>---</td>
<td>33</td>
<td>6.9×10⁸</td>
<td>2.9×10⁸</td>
</tr>
<tr>
<td>Cd-109</td>
<td>2</td>
<td>462d</td>
<td>9000d</td>
<td>---</td>
<td>---</td>
<td>50</td>
<td>2.1×10⁸</td>
<td>8.7×10⁷</td>
</tr>
<tr>
<td>In-111</td>
<td>3b</td>
<td>2.8d</td>
<td>Indefinite</td>
<td>0.245 (94%)</td>
<td>0.171 (90%)</td>
<td>140</td>
<td>6.5×10⁷</td>
<td>2.7×10⁴</td>
</tr>
<tr>
<td>I-123</td>
<td>4</td>
<td>13.2h</td>
<td>138d</td>
<td>---</td>
<td>0.159(83.4%)</td>
<td>75</td>
<td>1.8×10⁸</td>
<td>7.6×10⁶</td>
</tr>
<tr>
<td>I-124</td>
<td>3a</td>
<td>4.18d</td>
<td></td>
<td>0.027 (30%) 0.511 (46%) 0.603 (59%)</td>
<td>---</td>
<td>205</td>
<td>3.2×10⁸</td>
<td>1.3×10³</td>
</tr>
<tr>
<td>I-125</td>
<td>2</td>
<td>60d</td>
<td>138d</td>
<td>0.027 (39%)</td>
<td>---</td>
<td>74</td>
<td>2.7×10⁸</td>
<td>1.1×10⁸</td>
</tr>
<tr>
<td>I-131</td>
<td>2</td>
<td>8d</td>
<td>138d</td>
<td>0.360 (81.2%)</td>
<td>---</td>
<td>77</td>
<td>1.8×10⁸</td>
<td>7.6×10⁶</td>
</tr>
<tr>
<td>I-132</td>
<td>4</td>
<td>2.3h</td>
<td></td>
<td>1.185 (18.9%)</td>
<td>0.670 (98.7%)</td>
<td>390</td>
<td>1.0×10⁸</td>
<td>4.2×10⁷</td>
</tr>
<tr>
<td>Cs-131</td>
<td>4</td>
<td>9.7d</td>
<td></td>
<td>---</td>
<td>34</td>
<td>4.4×10⁸</td>
<td>1.9×10⁸</td>
<td>3.4×10⁷</td>
</tr>
<tr>
<td>Cs-137</td>
<td>3a</td>
<td>30y</td>
<td>70d</td>
<td>0.510 (94.6%)</td>
<td>0.660 (Note 2)</td>
<td>103 (Note 2)</td>
<td>3.0×10⁸</td>
<td>1.2×10⁷</td>
</tr>
<tr>
<td>Nuclide</td>
<td>Radio-toxicity group</td>
<td>Half-life</td>
<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>
<tr>
<td>--------------</td>
<td>----------------------</td>
<td>----------</td>
<td>----------------------</td>
<td>-----------------------------</td>
<td>-----------------------</td>
<td>--------------------</td>
<td>---------------------------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>µSv/h $\dagger$</td>
<td>Bq</td>
<td>Bq/m³</td>
</tr>
<tr>
<td>Sm-153</td>
<td>3b</td>
<td>46.7h</td>
<td></td>
<td>0.690 (43%) 0.640 (35%)</td>
<td>0.103 (28%)</td>
<td>24</td>
<td>2.9x10^7</td>
<td>1.2x10^4</td>
</tr>
<tr>
<td>Dy-165</td>
<td>4</td>
<td>2.33h</td>
<td></td>
<td>1.19 (14%) 1.29 (83%)</td>
<td>---</td>
<td>6.2</td>
<td>2.3x10^3</td>
<td>9.6x10^4</td>
</tr>
<tr>
<td>Yb-169</td>
<td>3a</td>
<td>32.0d</td>
<td></td>
<td>---</td>
<td>0.590 (35%)</td>
<td>88</td>
<td>8.3x10^7</td>
<td>3.5x10^7</td>
</tr>
<tr>
<td>Ir-192</td>
<td>3a</td>
<td>74d</td>
<td>20d</td>
<td>0.540 (41%) 0.670 (48%)</td>
<td>0.320 (82.8%) 0.468 (48%)</td>
<td>160</td>
<td>4.1x10^5</td>
<td>1.7x10^3</td>
</tr>
<tr>
<td>Au-198</td>
<td>3b</td>
<td>2.7d</td>
<td>120d</td>
<td>0.960 (98.8%)</td>
<td>0.410 (95.5%)</td>
<td>79</td>
<td>1.8x10^6</td>
<td>7.6x10^3</td>
</tr>
<tr>
<td>Ti-201</td>
<td>4</td>
<td>3.04d</td>
<td></td>
<td>---</td>
<td>0.167 (10%)</td>
<td>24</td>
<td>2.6x10^4</td>
<td>1.1x10^4</td>
</tr>
<tr>
<td>Ra-226</td>
<td>2</td>
<td>1600y</td>
<td>1.64 x 10^4 d</td>
<td>---</td>
<td>---</td>
<td>3.2</td>
<td>9.1x10^7</td>
<td>3.8x10^5</td>
</tr>
<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>7.4x10^2</td>
<td>3.1x10^4</td>
</tr>
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<td>Mixtures:</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<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>5.1x10^2</td>
<td>2.1x10^4</td>
</tr>
<tr>
<td>Ra-226+d (Note 3)</td>
<td>2</td>
<td>1600y</td>
<td>3.27 (Note 2)</td>
<td>0.8 (Note 4)</td>
<td>223</td>
<td>5.0x10^4</td>
<td>2.1x10^4</td>
<td></td>
</tr>
<tr>
<td>Th metal (freshly chemically separated thorium – Th-232 + Th-228)</td>
<td>4</td>
<td>1.4x10^10y</td>
<td></td>
<td>0.04 0.33 1.28 1.52 1.80 2.25</td>
<td>0.24 0.58 0.91 0.97 2.61</td>
<td>340 (Note 6)</td>
<td>3.1x10^3 (Note 7)</td>
<td>1.3x10^3</td>
</tr>
<tr>
<td>Th-ore (Note 5)</td>
<td>4</td>
<td>--</td>
<td></td>
<td>0.04 0.33 1.28 1.52 1.80 2.25</td>
<td>0.24 0.58 0.91 0.97 2.61</td>
<td>340 (Note 6)</td>
<td>3.1x10^3 (Note 7)</td>
<td>1.3x10^3</td>
</tr>
<tr>
<td>U metal (freshly chemically separated uranium – U-238 + U-234)</td>
<td>4</td>
<td>4.5x10^9y</td>
<td></td>
<td>3.2x10 3 1.3x10 0 4.3x10 5</td>
<td>0.02 0.06 0.19 0.67 0.73 1.51 1.54 2.28</td>
<td>150 (Note 8)</td>
<td>3.5x10^3</td>
<td>1.5x10^4</td>
</tr>
<tr>
<td>U-ore (Note 5)</td>
<td>4</td>
<td>---</td>
<td></td>
<td>0.02 0.06 0.19 0.67 0.73 1.51 1.54 2.28</td>
<td>0.05 0.30 0.35 0.61 0.80 1.12 1.76</td>
<td>150 (Note 8)</td>
<td>3.5x10^3</td>
<td>1.5x10^4</td>
</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.
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


