# Physical Hazards: Ionising Radiation

Core Body of Knowledge for the Generalist OHS Professional

Safety Institute of Australia Ltd

Australian OHS Education Accreditation Board

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The OHS Body of Knowledge for Generalist OHS Professionals has been developed under the auspices of the **Health and Safety Professionals Alliance**

The Technical Panel established by the Health and Safety Professionals Alliance (HaSPA) was responsible for developing the conceptual framework of the OHS Body of Knowledge and for selecting contributing authors and peer-reviewers. The Technical Panel comprised representatives from:

**The Safety Institute of Australia** supported the development of the OHS Body of Knowledge and will be providing ongoing support for the dissemination of the OHS Body of Knowledge and for the maintenance and further development of the Body of Knowledge through the Australian OHS Education Accreditation Board which is auspiced by the Safety Institute of Australia.

# Synopsis of the OHS Body of Knowledge

### Background

A defined body of knowledge is required as a basis for professional certification and for accreditation of education programs giving entry to a profession. The lack of such a body of knowledge for OHS professionals was identified in reviews of OHS legislation and OHS education in Australia. After a 2009 scoping study, WorkSafe Victoria provided funding to support a national project to develop and implement a core body of knowledge for generalist OHS professionals in Australia.

### Development

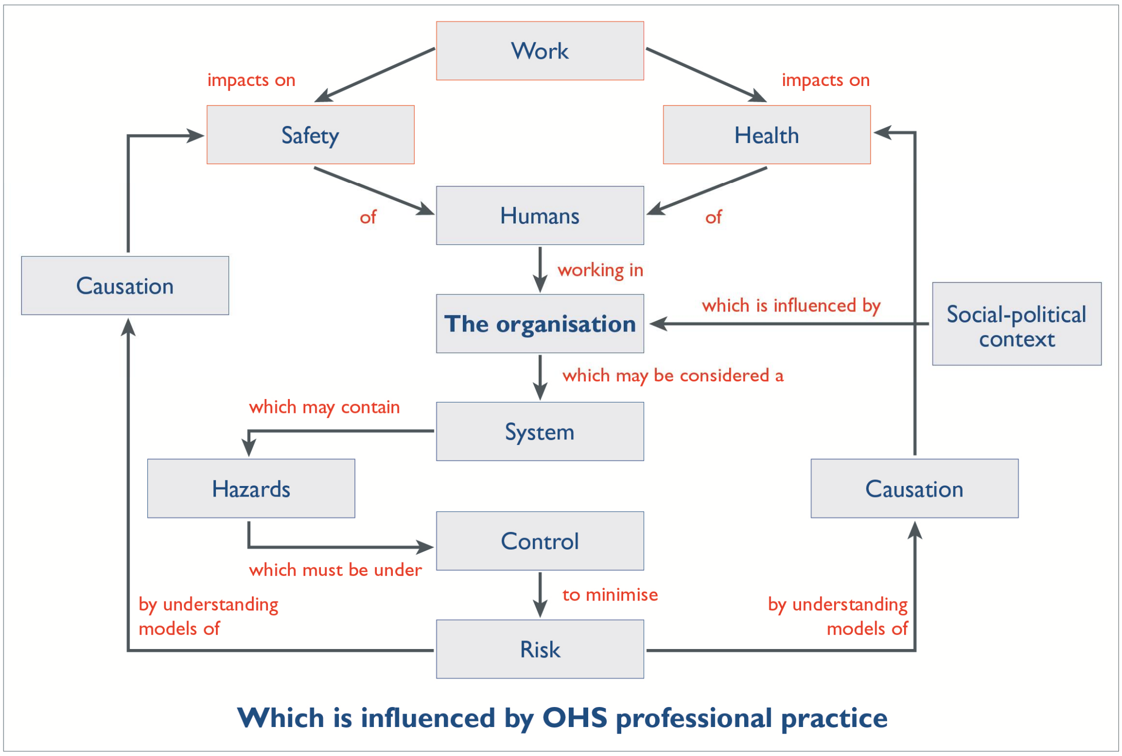
The process of developing and structuring the main content of this document was managed by a Technical Panel with representation from Victorian universities that teach OHS and from the Safety Institute of Australia, which is the main professional body for generalist OHS professionals in Australia. The Panel developed an initial conceptual framework which was then amended in accord with feedback received from OHS tertiary-level educators throughout Australia and the wider OHS profession. Specialist authors were invited to contribute chapters, which were then subjected to peer review and editing. It is anticipated that the resultant OHS Body of Knowledge will in future be regularly amended and updated as people use it and as the evidence base expands.

### Conceptual structure

The OHS Body of Knowledge takes a ‵conceptual′ approach. As concepts are abstract, the OHS professional needs to organise the concepts into a framework in order to solve a problem. The overall framework used to structure the OHS Body of Knowledge is that:

> **Work** impacts on the **safety** and **health** of humans who work in **organisations**. Organisations are influenced by the **socio-political context**. Organisations may be considered a **system** which may contain **hazards** which must be under control to minimise **risk**. This can be achieved by understanding **models causation** for safety and for health which will result in improvement in the safety and health of people at work. The OHS professional applies **professional practice** to influence the organisation to being about this improvement.

This can be represented as:




**Audience**

The OHS Body of Knowledge provides a basis for accreditation of OHS professional education programs and certification of individual OHS professionals. It provides guidance for OHS educators in course development, and for OHS professionals and professional bodies in developing continuing professional development activities. Also, OHS regulators, employers and recruiters may find it useful for benchmarking OHS professional practice.

**Application**

Importantly, the OHS Body of Knowledge is neither a textbook nor a curriculum; rather it describes the key concepts, core theories and related evidence that should be shared by Australian generalist OHS professionals. This knowledge will be gained through a combination of education and experience.

**Accessing and using the OHS Body of Knowledge for generalist OHS professionals**

The OHS Body of Knowledge is published electronically. Each chapter can be downloaded separately. However users are advised to read the Introduction, which provides background to the information in individual chapters. They should also note the copyright requirements and the disclaimer before using or acting on the information.

# Physical Hazards: Ionising Radiation

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**Core Body of Knowledge for the Generalist OHS Professional**

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# Physical Hazards: Ionising Radiation


## Abstract

Despite increased use of radiation in the workplace since the 19th century, the topic is associated with fear and lack of understanding in the community. While the level of natural background radiation makes it difficult to assess the impact of exposure to work-related radiation, the damage to the body is dose-related and cumulative, often with a long latency period. Thus the hazards and level of risk should be identified and managed. There is a legislative requirement for users of radiation sources to be licensed and for suitably trained *responsible persons* to be appointed; consequently, this chapter provides a broad overview of radiation hazards relevant to the generalist OHS professional. Excluding research and medical applications as specialist areas, OHS professionals are most likely to encounter radiation sources in industries such as construction, mining and manufacturing. This chapter reviews the physics of radiation and how ionising radiation can cause damage to the body. It outlines dose limits and risk assessment for radiation hazards, and cites relevant legislation and standards. Principles of radiation protection ï justification, limitation and optimisation ï are combined with exposure-limiting factors ï time, distance and shielding ï to develop a hierarchy of control. Finally, implications for OHS practice are discussed.



**Keywords:**

ionising radiation, dose, ALARA

# Contents

# 1 Introduction

Radiation[1] is used in many fields of human endeavour. Since the late 19th century, the use of radiation has increased significantly in medicine, the military, food preparation, power generation, and industry. However, a general fear of radioactivity and radiation exists in the wider community, largely due to a lack of knowledge about the subject. Events such as the nuclear weapon detonations over Hiroshima and Nagasaki during World War II, the Three-Mile Island accident in 1979, the Chernobyl accident in 1986 and the 2011 tsunami-impacted Fukushima reactor add to the level of public anxiety.

The science of radiation protection is more than 100 years old and, as a result, radiation is perhaps one of the best understood of all the agents able to inflict damage to living organisms. The field has well-established protocols for dose limitation, measurement and reporting. However, as with many other agents, determining the harmful effects (if any) of the typically low doses of radiation received in routine daily activities is a very difficult field of science (see, for example, EPA, 2011a) that can cause divisions between sections of the community. Further, as new technologies emerge that utilise the physical properties of radiation the health effect data from exposure can be incomplete and heightened levels of anxiety may occur.

Understanding the nature of radiation and radioactivity requires a solid grasp of fundamental scientific knowledge commensurate with the increasing complexity of the possible exposure scenarios. Further, each State and Territory requires the appointment of a *responsible person* (colloquially termed a Radiation Safety Officer[2]) approved by the relevant statutory authority before sources of radiation can be owned, used, transported, stored or disposed of. In most circumstances, approval to become a *responsible person* can be gained through successful completion of a specialised short course and passing a licensing examination conducted by the relevant statutory authority.

This chapter provides an overview of the broad field of radiation protection as it might be relevant to the generalist OHS professional. It assumes the reader has a basic understanding of the principles of nuclear science, including atomic structure and isotopes, and the structure and function of the human body at the cellular and organ level sufficient to understand how radiation causes damage to the human body.[3] It is not intended to prepare an OHS professional for appointment as a *responsible person*; this requires specialist knowledge acquired through formal learning. Similarly, the chapter does not

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[1] In this chapter the term ‘radiation’ refers exclusively to **ionising radiation**, unless otherwise identified.

[2] The term Radiation Safety Officer is not used in legislation or current guidance material in some jurisdictions, eg: Victoria. It was used in superseded legislation, e.g. the *Health (Radiation Safety) Regulations* 1994 (Vic) and guidance material for management plans relating to those regulations. However, the term readily describes the role of managing licence requirements for radiation sources.

[3] See *OHS BoK* Foundation Science.

delve into highly specialised areas such as the uranium fuel cycle, nuclear power generation, medical physics or military applications.

### 1.1 Definitions

The following definitions provided by the US Centers for Disease Control and Prevention (CDC, 2006) are relevant to a discussion of radiation hazards:

> **Absorbed dose:** the amount of energy deposited by ionizing radiation in a unit mass of tissue. It is expressed in units of joule per kilogram (J/kg) and called ñgrayò (Gy).
>
> **Background radiation:** ionizing radiation from natural sources, such as terrestrial radiation due to radionuclides in the soil or cosmic radiation originating in outer space.
>
> **Dose equivalent:** a quantity used in radiation protection to place all radiation on a common scale for calculating tissue damage. Dose equivalent is the absorbed dose in grays times the quality factor. The quality factor accounts for differences in radiation effects caused by different types of ionizing radiationé The sievert (Sv) is the unit used to measure dose equivalent.
>
> **Effective dose:** a dosimetric quantity useful for comparing the overall health effects of irradiation of the whole body. It takes into account the absorbed doses received by various organs and tissues and weighs them according to present knowledge of the sensitivity of each organ to radiationé The unit of effective dose is the sievert (Sv); 1 Sv = 1 J/kg.
>
> **Half-life:** the time any substance takes to decay by half of its original amount.
>
> **Ion:** an atom that has fewer or more electrons than it has protons causing it to have an electrical charge and, therefore, be chemically reactive.
>
> **Ionization:** the process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiation can cause ionization.
>
> **Ionizing radiation:** any radiation capable of displacing electrons from atoms, thereby producing ions. High doses of ionizing radiation may produce severe skin or tissue damage.[4]
>
> **Isotope:** a nuclide of an element having the same number of protons but a different number of neutrons.
>
> **Radiation:** energy moving in the form of particles or waves. Familiar non-ionising radiations are heat, light, radio waves, and microwaves. Ionizing radiation is a very high-energy form of electromagnetic radiation and particles.
>
> **Radioactive material:** material that contains unstable (radioactive) atoms that give off radiation as they decay.
>
> **Radioactivity:** the process of spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles often accompanied by gamma rays. This process is referred to as decay or disintegration of an atom.

In addition, **ALARA/ALARP** refers to a principle of radiation protection that stipulates that radiation doses should be kept As Low As Reasonably Achievable / Practicable, taking

[4] The common industrial ionising radiation likely to be encountered by the OHS professional would be alpha and beta particles, neutrons, gamma and x rays.

into account social and technological factors (see, for example, ARPANSA, 2002; DMP, 2010).

## 2 Historical context

In 1895, German physicist Willhelm Röntgen discovered x-rays. The following year, French physicist Henri Becquerel discovered natural ionising radiation emanating from uranium ore and, in 1898, French physicist Marie Curie isolated the radioactive elements of polonium and radium from the uranium-bearing ore pitchblende, and coined the term όradioactivityô to describe the energy the isotopes emitted. (See, for example, Kathren & Ziemer, 1980; NSD Berkeley Lab, 2000.)

The hazardous impacts of radiation did not emerge until the above-mentioned discoveries of the 1890s when it became apparent that some form of protection was required to avoid ill-health effects resulting from over-exposure to sources of radiation. As early as 1897, reports were made of burns (usually to the hands) sustained by x-ray technicians. Awareness of the harmful effects of exposure led to the first attempt, in 1902, to codify limits of exposure in what became known as the Rollins Code (Kathren & Ziemer, 1980).

As chronicled by Mullner (1999), American electrical engineer William J. Hammer exploited the luminescent property of radium and invented a glow-in-the-dark paint in 1902. Over the next decade, several patents were issued for όradioluminous compounds,ô which were applied to the hands and faces of increasingly popular όradium watches.ô During World War I, the demand for instruments with radium-painted dials increased significantly and, as a result, large numbers of workers (mostly young women) were employed in factories to increase their manufacture. Painting was done by hand, with the majority of workers licking the tips of their brushes to maintain a fine point. Unfortunately, this meant that many workers ingested the radioactive radium; during the 1920s, it became apparent that many of the dial painters were dying prematurely or suffering from a variety of acute and chronic diseases, including cancers of the jaw. This led to the 1941 publication of the US National Bureau of Standards handbook *Safe Handling of Radioactive Luminous Compound*, which stipulated the maximum permissible body burden (a precursor of an exposure standard) for radium (Mullner, 1999; Winkelstein, 2002).

By the 1930s, interest was escalating in the use of uranium and in the health effects of its radioactive decay products, radium and the noble gas radon. The US National Research Council (NRC) documented that, as early as the 1500s, a wasting disease known as *Bergkrankheit* (όmountain diseaseô) had been noted in the Erz Mountains of eastern Europe and, in 1879, had been recorded as ñan occupational hazardò of metal mining in the area (NRC, 1991, p. 11). Studies in the early 1900s established that the wasting disease was lung cancer and, in the 1930s, excess cases of lung cancer were statistically proven in the underground metal miners. Measurements of radon in the underground workings returned concentrations that would be considered high by todayôs standards; however, it was not until the 1950s that the causal link between radon exposure and lung cancer became generally accepted (NRC, 1991).

Because radon gas is ubiquitous in the environment, exposures are a concern for the general population as well as the underground mining industry. Since the 1950s, particular attention has been paid to radon in buildings, and especially in air-tight spaces (e.g. cellars), as insufficient ventilation may lead to a build up of concentrations and therefore elevated doses (ARPANSA, 2002; NRC, 1991).

As medical and industrial use of radiation increased in the latter half of the 20th century, so too did the potential for accidental exposures of workers and members of the public to radiation sources. The 1980s saw several infamous events including: the use of steel scavenged from a nuclear reactor in the construction of apartments in Taiwan (1982); a salvaged radiotherapy source that was smelted with 5000 tonnes of steel and used to manufacture table legs in Mexico (1983); and scavenging of a radiotherapy machine from an abandoned clinic in Goiania, Brazil (1987) (see, for example, IAEA, 1988; Nénot, 2002). These accidental exposures reinforced the need for the international radiation community to ensure compliance in the safe use of radiation and radioactive materials (IAEA, 2008).

Despite these accidents, safe use of radiation occurs across the globe, in many and varied applications. Like any other hazard, the associated risks have to be assessed and controlled.

## 3 Extent of the problem

It is very difficult to assess the extent of the problem arising from the typically low levels of workplace exposure to radiation. The damage to the body caused by chronic exposures to radiation is dose-related, the effects are cumulative, and there is often a latency period of many years before illness or injury is manifested (see, for example, ARPANSA, 2005; EPA, 2011a; NRPB, 2001).

Another factor complicating any assessment of the impact of exposure to radiation in the workplace is that everybody is exposed to varying low levels of natural radiation as part of daily life (ARPANSA, 2011a; RHSAC, 2005). While the principles of radiation protection protect workers from the increased risks associated with exposures in the workplace, it is important to understand the nature and impact of this natural background radiation.

All the isotopes of elements with an atomic number greater than 83 are radioactive (see, for example, Hart, 2005). The elements potassium (K-40), rubidium (Rb-87), thorium (Th-232) and uranium (U-235 and U-238) are known collectively as *primordial radionuclides* because of their long half-lives and because all contribute to background radiation

(RHSAC, 2005). In some areas, the primordial radionuclides have become concentrated and may exhibit dose-rates as much as a hundred times the global average. Studies of populations living in the areas of elevated primordial radionuclide concentrations show no statistically significant impact upon life expectancy or increase in chronic health effects (RHSAC, 2005). These findings challenge the current system of radiation dose limitation, and have triggered a concept called *radiation hormesis*, which theorises that rather than causing damage to health, radiation doses at low levels may actually be beneficial to exposed populations and essential to evolution of our species (Feinendegen, 2005; Hart, 2005). However, the concept of radiation hormesis has not been accepted by standard setting bodies such as the US National Council on Radiation Protection and Measurements.[5]

The Earth is constantly bathed in cosmic rays arising from extraterrestrial events such as solar flares and sun spots. The dose rate from cosmic rays increases with height above sea level. As a result, a person living in Denver, Colorado (the ómile highô city) receives about twice as much radiation dose from cosmic radiation as the average person living at sea level (Hart, 2005). Dose rates also vary with latitude and increase with distance from the equator due to differences in the thickness of the atmosphere. An airline crew flying between 10,000 and 14,000 metres at the equator will receive radiation doses two to three times smaller than a crew flying at the same altitude over one of the poles. Although airline crews receive radiation doses elevated above the normal background level, studies suggest that there are no statistically significant health effects arising from the increase in exposure (ARPANSA, 2011a; HPS, 2011; United Airlines Medical Department 2001 as cited in AFA-CWA, 2011).

Construction workers will encounter low concentrations of primordial radionuclides in building materials such as cement and bricks; normally, these radiation doses will be correspondingly very low (see, for example, USNRC, 2011). Another possible exposure scenario occurs during dry blasting of surfaces using abrasive minerals such as garnet. The dust generated by the abrasive blasting action can contain fine particles, which may be inhaled and deposited in the lungs. Importantly, if dry blasting techniques must be used (wet techniques are favoured), appropriate respiratory protective equipment must be worn to limit potential radiation exposures to the internal organs (see, for example, WorkSafe Western Australia, 2000).

Workers in the manufacturing and mineral processing industries may encounter sources of radiation used in quality control. Gauges that measure the absorption of gamma rays may be used to measure the density of fluids in pipes, or how much material has been dispensed into a container such as a tin or can. Gauges using beta radiation can be used to measure

[5] NCRP Report No136 ï Evaluation of the Linear-Non-threshold Dose-response Model for Ionising Radiation.

the thickness of paper or card in the paper manufacturing industry. The road construction industry often utilises a combination of neutron and gamma ray scattering to conduct measurements of soil density and water content (ARPANSA, 2004; EPA, 2010). X-rays may be used in laboratories to conduct sample analysis, and either x-rays or gamma rays can be applied in industrial radiography as a non-destructive technique for testing the integrity of welds, joins or seals (NRC, 2008).[6]

Also, radiation and radioactive substances are found in the office environment. Smoke detectors, many of which use small radioactive sources, are mandatory in modern buildings. Also, while modern buildings use photo-luminescent materials in their exit signs, many older buildings still have a exit signs that use the beta particle emissions from a radioactive isotope of hydrogen (H-3, commonly called tritium) to enable the sign to glow in the dark (Hart, 2004).

## 4. Understanding radiation

Understanding radiation requires basic knowledge of atomic structure, energy and how radiation may damage cells in the human body.[7] This section builds on this basic knowledge by reviewing the physics of radiation, and how radiation can cause damage to the human body.

### 4.1 The physics of radiation

Radiation is a descriptor for energy (in the form of either particles or waves) travelling through space or another medium. The energy is emitted from the source and radiates in straight lines and in all directions. If the radiation is an electromagnetic wave, it will travel at the speed of light. Because of the way the energy is radiated, radiation is relatively straightforward to detect and measure and inferences can be made about its source. The properties of the energy emitted will determine the way it interacts with matter (and living tissue) and therefore its measurement technique and requirements for regulation (ARPANSA, 2011b).

There are two types of radiation: ionising and non-ionising.[8] Ionisation is the process by which a stable atom or a molecule loses or gains an electron(s), thereby acquiring an electric charge or changing an existing charge (ARPANSA, 2002). An atom or molecule with an electric charge is called an ion, which may behave differently, electrically and chemically, from a stable atom or molecule. The altered behaviour may lead to new possibly undesired molecules, a change in the conductive properties of the material in the vicinity of the ion, a release of energy, or a combination of these effects. In the human body, these effects may lead to changes in the structure or behaviour of cells. Therefore,

[6] For more information, see ARPANSA, 2004; IAEA, 2005; NATA, 2011.
[7] See *OHS BoK* Foundation Science.
[8] See also *OHS BoK* Physical Hazards: Non-Ionising Radiation - Electromagnetic.

ionising radiation has sufficient energy to be able to displace an electron from its orbit around an atom and, conversely, non-ionising radiation does not have sufficient energy to displace electrons. (See ARPANSA, 2012a.)

*Ionising radiation* can occur in one of two forms: particulate or electromagnetic. Particulate ionising radiation is emitted when components of the structure of an atom are ejected, artificially or naturally. The emitted particles can be:

- alpha particles, which include two protons and two neutrons (ionised helium)
- beta particles, which are essentially electrons
- neutrons
- gamma rays and x rays which are pure energy (photons). (ARPANSA, 2012b)

The normal cautionary sign for ionising radiation is given in Figure 1.

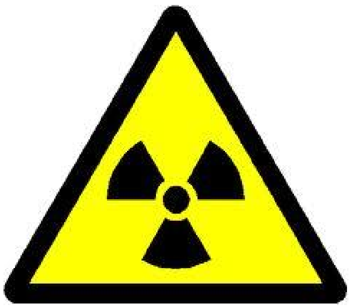

**Figure 1: Warning sign for ionising radiation**

*Non-ionising radiation* consists of parts of the electromagnetic-spectrum (Figure 2), which includes radio waves, microwaves, infra-red, visible and ultraviolet light, together with sound and ultrasound (ICNIRP, 2002). The electromagnetic spectrum also includes *ionising electromagnetic radiation* (x and gamma rays).

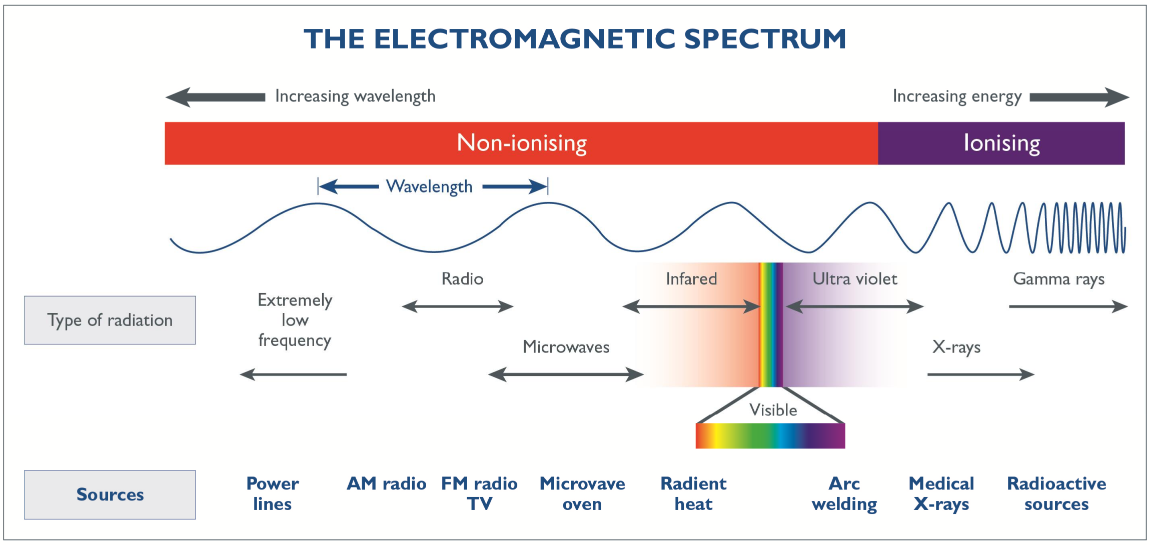


**Figure 2: The electromagnetic spectrum (modified from ARPANSA, 2012a)**

## 4.2 Types of electromagnetic ionising radiation

Ionising radiation has more energy than non-ionising radiation such that it can cause chemical changes by interacting with an atom to remove tightly bound electrons from the orbit of the atom, causing the atom to become charged or ionised. (WHO, 2012).

The types of ionising electromagnetic radiation are categorised according to their wavelength.

### 4.2.1 Ultraviolet

The dividing line between ionising and non-ionising radiation in the electromagnetic spectrum falls in the ultraviolet portion of the spectrum and while most UV is classified as non-ionising radiation, the shorter wavelengths from about 150 nm (UV-C or ôFarô UV) are ionising. UV-C from the sun is nearly all absorbed by the ozone layer.

### 4.2.3 X-rays

X-rays are produced when electrons strike a target or when electrons are rearranged within an atom (ARPANSA, 2012a). X-rays have a wavelength smaller than about 10 nm. In medical applications X-ray machines are specifically designed to take advantage of the difference of absorption of x-rays between bone and soft tissue. In the industrial arena, non-destructive testing (NDT) using x-ray machines introduced into pipes or vessels to check for integrity, or to check welds or joints is commonly used.

### 4.2.4 Gamma rays

Gamma (ɔ) radiation has a wavelength of less than 0.01nm and is comprised of photons emitted by the nucleus of some substances (radionuclides) following radioactive decay. Photons in gamma radiation are the most energetic and so most penetrating in the electromagnetic spectrum (ARPANSA, 2012b).

The penetrating power of gamma radiation has a range of industrial uses:

- Measuring and controlling the flow of liquids in industrial processes (Cesium-137)
- Ensuring proper fill level for packages of food, drugs and other products (Cesium-137)
- Sterilising medical equipment and pasteurising certain foods (Cobalt-60)
- Gauging the thickness of metal in steel mills (Cobalt-60)
- Fluid level gauges (Cobalt-60)
- Distance measuring devices (Cobalt-60). (ARPANSA, 2012b).

Gamma rays are difficult to stop, but they can be absorbed by a sufficiently thick layer of dense material such as lead or depleted uranium.

## 4.3 The impact of ionising radiation on the body

Whenever ionising radiation interacts with matter, small amounts of energy from the radiation are quickly transferred to the affected material. Linear Energy Transfer (LET) ï ña measure of an average energy loss along the path of radiationò (Olko, 2006, p. 207) ï is dependent upon the type of radiation and the energy it carries. High-LET radiations (such as alpha particles) ódeliverô a dose of radiation much more effectively than Low-LET radiations (such as x-rays or gamma rays). Radiation dose calculations use a variable called the Quality Factor to recognise the LET properties of the radiation. (See, for example, Shultis & Faw, 2010.)

Ionising radiation has the ability to induce free radicals, such as the hydroxide ion, in living tissues. Free radicals can move rapidly within the body and may cause chemical changes to molecules with which they interact. Also, ionising radiation can interact at the cellular level and disturb the DNA within the cell structure.

In the human body, some organs are more sensitive to radiation-induced damage than others. Therefore it is important to consider which organ has been ótargetedô by the radiation and apply a ótissue weighting factorô to properly calculate the radiation dose received (Wrixon, 2008). For example, bone marrow and lung tissue are deemed to be more radio-sensitive than skin, and carry a ótissue weighting factorô 12 times that applicable to skin exposures (ICRP, 2007). This is important in medical applications (e.g.

radiotherapy) and in dose estimation when internal exposures are a factor (e.g. inhalation of radioactive dusts encountered in mining or abrasive blasting activities).

If the normally efficient repair mechanisms within the body are not able to attend to the damage caused by the radiation or the free radicals, the cell may be modified (mutated)[9] or die. Modified cells have a small probability of manifesting as a cancer or being passed on to future generations if the ovaries or testes are affected; also, the impacts of multiple cell deaths can lead to failure of the organ in which the exposure to radiation occurred. The probability of cell damage remaining unrepaired increases with dose, and is dependent upon whether the dose was acute or chronic.

> A single accidental exposure to a high dose of radiation during a short period of time is referred to as an acute exposure, and may produce biological effects within a short period after exposure. These effects are:
>
> - Nausea and vomiting
> - Malaise and fatigue
> - Increased temperature
> - Blood changes
> - Bone marrow damage
> - Damage to cells lining the small intestine
> - Damage to blood vessels in the brain (University of Toronto, 2004).

Also, there may be delayed effects of acute exposure, including various forms of cancer (leukaemia, bone cancer, thyroid cancer, lung cancer) and genetic defects (malformations in children born to parents exposed to radiation) (University of Toronto, 2004). In radiological situations involving the induction of cancer, there is a latency period between the radiation exposure and the onset of disease. For example, the minimum latency period for leukaemia produced by radiation is two years and other types of cancer can take ten years or more to manifest (University of Toronto, 2004).

LET, the tissue weighting factor, and whether the dose is delivered in a short or extended time period complicate epidemiological studies. There is consensus in the radiation protection community that a dose-response relationship exists for high doses delivered over short periods of time. The relationship has been observed in survivors of the atomic weapon detonations over Hiroshima and Nagasaki, and high-dose accidental exposures. (Bertell, 1996; Fabrikant, 1981). However, debate ensues over the extension of these observable impacts to low doses delivered over elongated exposure periods that are typically encountered in contemporary workplaces (Brenner & Raabe, 2001). Nonetheless, the radiation community has long subscribed to an approach called the Linear No-Threshold [10] hypothesis (Figure 3) that assumes every dose of radiation (no matter how small) carries with it some level of risk (ARPANSA, 2005; USNRC, 2011).

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[9] See *OHS BoK* Foundation Science.

[10] Referred to as ñLinear Non Thresholdò in some references.

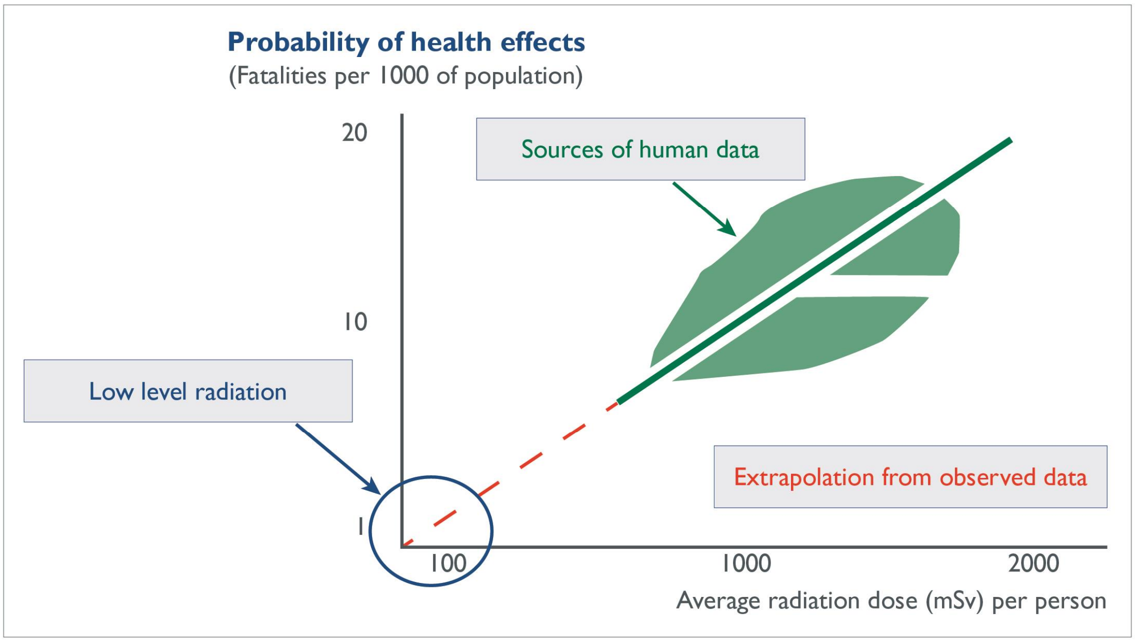


**Figure 3: The Linear No-Threshold hypothesis (Hewson & Ralph, 1991)**

## 4.4 Radiation dose and dose limits

The International Commission on Radiological Protection (ICRP, 2007) and other international organisations collaborate to publish recommended dose limits and explanations of the concepts underlying the determination of radiation doses.

The following definitions are important in understanding the concept of radiation doses arising from exposure to ionising radiation.[11]

### 4.4.1 Absorbed dose

When radiation strikes a material, it will deposit energy in that material through a variety of interactions. A measure of the amount of radiation that a material has received is the quantity called *absorbed dose*, the amount of ñenergy absorbed per unit massò (ARPANSA, 2002, p. r-2). The unit of absorbed dose is the gray (Gy), which is equal to an energy deposition of 1 J/kg. However, because energy deposition varies for different materials, the material also needs to be specified; for example, as óin air,ô óin water,ô óin an organô or óin tissue.ô

[11] See also section 1.1.

### 4.4.2 Equivalent dose

One difficulty with the use of absorbed dose for radiation protection purposes is that the biological effect of an absorbed dose in tissue is dependent on the type and energy of the incident radiation. To overcome this difficulty, a quantity called *equivalent dose* is used. Equivalent dose uses a weighting factor, which is representative of the relative biological effectiveness of that radiation in inducing health effects at low doses (ARPANSA, 2002). For example, electromagnetic radiation and electrons (beta particles) have a weighting factor of 1, whereas alpha particles have a weighting factor of 20. Equivalent dose is measured in millisieverts (mSv).

### 4.4.3 Tissue weighting factors and effective dose

To determine the dose to the human body, the impact of an exposure upon individual organs needs to be assessed. Some tissues and organs are more sensitive to radiation than others; to account for radio-sensitivity, a *tissue weighting factor* is applied specific to the organ in question. For example, bone marrow and the lungs have a weighting factor of 0.12, the liver and thyroid 0.04 and the skin 0.01.

If the whole body is exposed, a weighting factor of 1 applies (ICRP, 2007; ARPANSA, 2002), and the terms Effective dose and Equivalent dose are the same. Effective dose is measured in millisieverts (mSv).

### 4.4.4 Individual dose limits

It is important to recognise that dose limits are set so that any continued exposure just above the dose limits would result in additional risks that could be reasonably described as óunacceptableô in normal circumstances.

The effective dose limits for *ionising radiation* are:

Occupational exposures:

- 20 mSv per year (averaged over 5 calendar years)
- 50 mSv in any one single year.

Members of the public:

- 1 mSv in a year. (ICRP, 2007)

Regulations within jurisdictions (eg *Radiation Regulations* 2007 (Vic)) have also established Equivalent dose limits for the eye lens, skin and hands/feet (see section 5).

The dose limits as established by the ICRP (2007) are taken as being above natural background levels. Therefore, it is important that the radiation levels arising from natural background are determined prior to an exposure occurring.

### 4.5 Risk assessment for radiation exposures

In accordance with the Linear No-Threshold hypothesis, any risk assessment for exposure to radiation should be based on the principle that any amount of radiation exposure, no matter how small, can increase the chance of negative biological effects (e.g. cancer) (ARPANSA, 2005). The Linear No-Threshold hypothesis takes into consideration that the probability of negative health effects of radiation exposure increases with cumulative lifetime dose.

A downside to the Linear No-Threshold hypothesis is that radiology and other practices that involve use of radiation to bring evident benefits to society are swept up with the *every exposure involves an increased risk* model; consequently, the risk-versus-benefit equation can be skewed, so as to reduce the efficacy of radiation exposures (e.g. in medical applications).

The Linear Non-Threshold hypothesis is very conservative at low levels that typify radiation exposures encountered in the everyday workplace. Despite this conservatism, the principle of As Low As Reasonably Achievable /Practicable (ALARA/ALARP[12]) should be applied to radiation protection. For example, if a radiation density gauge is used in a manufacturing process, the source will be contained within a thick lead shield. However, some small amount of gamma radiation may still penetrate the lead barrier. The economic (and manual handling) cost of adding further lead shielding must be considered when assessing the adequacy of other controls to minimise the risk of radiation exposure, such as reducing exposure time and increasing the distance from employees (see section 6.2). At some point the cost-benefit analysis may demonstrate that some, albeit minimal, exposure may not be practicable to avoid. (ARPANSA, 2007)

## 5 Legislation and standards

The precise requirements for the use, handling, transport and storage of radioactive materials by licensed holders is highly regulated and, as noted in section 1, coverage of such operations is beyond the scope of this chapter.

Radiation and radioactive materials in the workplace present a hazard that falls within the provisions of the general duty of care of the employer to do what is reasonably practicable to minimise the risk of exposure. (See, Safe Work Australia, 2011, ss 18, 19). Outside the

[12] See *OHS BoK* Risk.

Workplace Health and Safety (WHS) legislation there are subtle differences in the regulatory framework applying to radiation protection. Each State and Territory has its own suite of radiation safety legislation, often applying different regulations to ionising sources of radiation exposures and, in some instances, separating mining and mineral processing from the core OHS legislative framework. Additionally, each State and Territory is responsible for regulating the use, handling, transport and storage of materials and goods that are capable of emitting radiation. They also require a trained *responsible person* to oversight the management of ionising radiation sources within workplaces. These requirements apply equally to ómanufacturedô items such as x-ray machines or density gauges and the mining and processing of naturally occurring radioactive minerals (e.g. uranium or mineral sands).

In 1999, the Australian Health Ministersô Conference endorsed the development of the *National Directory for Radiation Protection* (ARPANSA, 2011c, p. i) ñas the means of achieving uniformity in radiation protection practices between jurisdictions.ò As documented by ARPANSA (2011d), the first edition of the *National Directory* was approved by the Radiation Health Committee (RHC) in 2004; however, it did not include coverage of the mining and mineral processing industries. Subsequently in 2005, the *Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing* was incorporated into the *National Directory* that provides for uniform regulations across the country (ARPANSA, 2011c).

In 2010, the Radiation Health Committee reported that:

> Australiaõs Radiation Protection Standards are currently embodied in ARPANSAõs Radiation Protection Series publication 1 (RPS 1), *Recommendations for Limiting Exposure to Ionizing Radiation and National Standard for Limiting Occupational Exposure to Ionizing Radiation* (2002). RPS 1 is based on the *1990 recommendations of the International Commission on Radiological Protection* (ICRP) in its publication 60 (1991).
>
> In December 2007, ICRP published new recommendations (ICRP publication 103) and, as a result, the Radiation Health Committee (RHC) has commenced a process of reviewing the ICRPõs recommendations and revising RPS 1é The occupational and public dose limits in ICRP 103 have not changed.
>
> The RHC review will involve rewriting RPS 1 to take account of the ICRP recommendations and other international developments such as the IAEAõs [International Atomic Energy Agency] revision of the International Basic Safety Standards. (RHC, 2010)

The process of review by the RHC will ensure contemporary research and developments are acknowledged and, if deemed applicable, captured in the *National Directory*, which in turn will stimulate changes to State and Territory legislation.

The harmonisation of radiation-related legislation across the country via the *National Directory* endeavours to standardise dose limits, responsibilities of Government Ministers, authorisations and licenses, and competency requirements. The legislation is supported by the *Radiation Protection Series*, which is published by ARPANSA:

é to promote practices that protect human health and the environment from the possible harmful effects of radiation. ARPANSA is assisted in this task by its Radiation Health and Safety Advisory Council, which reviews the publication program for the *Series* and endorses documents for publication, and by its Radiation Health Committee, which oversees the preparation of draft documents and recommends publication.

There are four categories of publication in the *Radiation Protection Series*:

- Radiation Protection Standards
- Codes of Practice
- Recommendations
- Safety Guides

All publications in the *Radiation Protection Series* are informed by public comment during drafting, and Radiation Protection Standards and Codes of Practice, which may serve a regulatory function, are subject to a process of regulatory review. Further information on these consultation processes may be obtained by contacting ARPANSA. (ARPANSA, 2011c)

# 6 Control

Radiation protection can be divided into *occupational radiation protection* (for the protection of workers), *medical radiation protection* (for the protection of patients and the radiographer), and *public radiation protection* (for the protection of individual members of the public and the population as a whole). The types of exposure, as well as government regulations and legal exposure limits are different for each of these groups. As noted in section 1, the scope of this chapter is limited to the activities within the role of the generalist OHS professional and so does not extend to the specialist areas of medical radiation protection or workplaces that are licensed to handle radioactive materials.

## 6.1 Principles of radiation protection

In Australia, the Australian Radiation Protection and Nuclear Science Agency (ARPANSA) is the lead government agency. ARPANSA subscribes to the ICRP recommendations in that three underlying principles need to be considered before exposure to radiation occurs:

**Justification** involves a demonstration that there is a net benefit from a practice which leads to exposure to radiationé Only options which can be expected to do more good than harm are selectedé

**Optimization** is employed to make the best use of resources in reducing radiation risks, once a practice has been justified. The broad aim is to ensure that the magnitude of individual doses, the number of people exposed, and the likelihood that potential exposures will actually occur should all be kept as low as reasonably achievable, economic and social factors being taken into account (ALARA)é .

**Limitation** of dose or risk is used to place bounds on risk to individuals so that risks do not exceed a value which would be considered unacceptable for everyday, long-term exposure to radiationé (ARPANSA, 2002, pp. r-5 ï r-6).

## 6.2 Control of exposure

In a practical sense, there are three factors that can be applied to limit exposure to radiation:

**Time:** The amount of radiation exposure increases and decreases with the time people spend near the source of radiationé

**Distance**: The farther away people are from a radiation source, the less their exposureé As a rule, if you double the distance, you reduce the exposure by a factor of four. Halving the distance increases the exposure by a factor of fouré

**Shielding**: The greater the shielding around a radiation source, the smaller the exposureé The amount of shielding required to protect against different kinds of radiation depends on how much energy they have.
*Alpha:* A thin piece of light material, such as paper, or even the dead cells in the outer layer of human skin provides adequate shielding because alpha particles canôt penetrate it. However, living tissue inside body offers no protection against inhaled or ingested alpha emitters.
*Beta:* Additional covering, e.g. heavy clothing, is necessary to protect against beta-emitters. Some beta particles can penetrate and burn the skin.
*Gamma:* Thick, dense shielding, such as lead, is necessary to protect against gamma rays. The higher the energy of the gamma ray, the thicker the lead must be. (EPA, 2011b)

In combination, the three underlying principles outlined in section 6.1 and the concepts of time, distance and shielding can be construed as a hierarchy of control for radiation protection, with the concepts aligning as indicated in Table 1.

**Table 1: A hierarchy of control for protection**

| Hierarchy of Control | System of Radiation Protection |
|---|---|
| Elimination | Justification<br>If an exposure cannot be justified, it should not occur. |
| Substitution | Limitation and Optimisation<br>If risk assessments demonstrate that exposures will not be within limits or ALARA/P, alternative technologies should be utilised. |
| Engineering | Shielding and Distance<br>Shielding is a form of engineered barrier, whilst distance can be thought of as an application of segregation. |
| Administration | Distance and Time<br>Distance can be thought of in terms of planning and layout, while time can be thought of as limiting exposure periods and as a result sharing a dose amongst several individuals rather than one person receiving a large dose. |
| Personal Protective Equipment | Shielding<br>In this instance respiratory protection can prevent internal exposures arising from inhalation; clothing, full barrier suits can prevent direct exposure to the skin and glasses/goggles/helmets protect the lens of the eye. |

For more information on control of exposure to radiation, see ARPANSA, 2002.

## 7 Implications for OHS practice

The demands upon the generalist OHS professional in controlling exposure to radiation will vary with industry type, the source of radiation and exposure scenarios, and may be either relatively straightforward or extremely complex.

Regardless of the source of exposure or complexity, all licensed or registered users of sources of radiation will require the development of a Radiation Management Plan (see ARPANSA, 2004; State Government of Victoria, 2003). The requirements for a license apply equally to a device used in medicine, a process-control instrument used in manufacturing, or the extraction of a naturally occurring radioactive mineral (e.g. uranium). The Radiation Management Plan will outline the specifications for compliance, dose limitations, management of accidents and associated exposures, appointment of a *responsible person*, etc., in accordance with State or Territory regulatory requirements. In many circumstances, it will be necessary to source external expertise to assist in compliance with regulatory requirements, training of *responsible persons* or Radiation Management Plan development.

As the potential exposure scenarios and measurement of dose estimates increase in complexity, some regulatory authorities (e.g. in the mining and health industries) specify the need for tertiary qualifications and relevant industry experience for approval as a *responsible person.*[13] The *responsible person* is accountable for ensuring exposures are monitored in accordance with the ALARA principle, measuring doses, informing the relevant statutory authorities, complying with license specifications, liaising with stakeholders and responding to accidental exposure scenarios.

In the event that a risk assessment indicates that licensing is not required and therefore appointment of ‘users’ or *responsible persons* is not applicable, a Radiation Management Plan need not be developed. However, areas in workplaces where exposure to radiation may occur should be signposted, and the hazard subject to appropriate risk-management treatment.

Because radiation cannot be measured quantitatively by the human senses, instrumentation is needed to detect the presence of, type and nature of the radiations. The nature of instrumentation can vary from simple to very complex and the generalist OHS professional

[13] See, for example, *Criteria for assessment of applications from approved testers,* issued by Victorian Department of Health, Dec 2011, in relation to such positions specified within the *Radiation Act* 2005 (Vic).

will usually require specialist training or access to specialist advice to determine the most appropriate type of instrumentation and associated protocols.

## 8 Summary

Radiation has many useful applications in industry and medicine; however, over-exposure has been demonstrated to be harmful to human health, leading to an international system of risk assessment and dose limitation.

Although a natural phenomenon, radiation is not well understood by the community at large. Events such as the 2011 Fukushima tsunami-induced reactor shutdown in Japan keep the public alarmed about the health effects of possible exposure to sources of radiation. In the contemporary Australian context, a Fukushima-like event is highly unlikely; however, the use of radiation is so widespread in the workplace that the likelihood of low-scale accidental exposures is of significant concern. As a result, the use of radiation in the workplace is highly regulated; it is imperative to ensure strict legal enforcement of regulations, and best practice in the qualifications and competencies of users of sources of radiation.

While, in specified circumstances, users of radioactive material must be licensed and there must be an appropriately qualified *responsible person*, generalist OHS professionals have a role in identification and management of radioactive hazards. They should understand the basic science of radioactivity and electromagnetic radiation, how it causes damage, the nature of the damage and the principles of control as a basis for providing advice in less complex situations, for identifying when a *responsible person* or specialist advisor is required, and for working with and supporting the specialist advisor.

## Key thinkers and resources

The field of radiation protection is under constant review by international and national authorities. The following organisations contribute to the continued evolution of the field:

- International Commission on Radiological Protection (ICRP): www.icrp.org/
- United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR): www.unscear.org/
- International Atomic Energy Agency (IAEA): www.iaea.org/
- Australian Radiation Protection and Nuclear Science Agency (ARPANSA): www.arpansa.gov.au/ (the key source of technical information in Australia on radiation matters)
- Society for Radiological Protection (SRP): www.srp-uk.org/

- Australasian Society for Radiological Protection (ARPS): www.arps.org.au/

The jurisdiction regulator should also be utilised as a source of information and advice.

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