SESLHD PROCEDURE COVER SHEET

Health
South Eastern Sydney
Local Health District

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SUMMARY	Information on the nature of radiation, the sources of radiation and the risks associated with radiation exposure.

Feedback about this document can be sent to SESLHD-Policy@health.nsw.gov.au

1. POLICY STATEMENT

The South Eastern Sydney Local Health District (SESLHD or LHD) is committed, through a risk management approach, to protecting employees, contractors, students, volunteers, patients, members of the public and the environment from unnecessary exposure to radiation arising from systems and processes which use radiation apparatus and radioactive substances, whilst maintaining optimum diagnostic and therapeutic quality, therapeutic efficacy and patient care.

This document provides information on the nature of radiation, the sources of radiation and the risks associated with radiation exposure. It also provides the objectives of radiation protection.

2. BACKGROUND

In the Policy and associated Procedures, reference will be made to the various types of radiation, and the units used for their measurement. SI units will be used throughout the documents. All medical administrations of radiation and/or radioactive materials are legally required to be ordered, measured and dispensed in SI units.

2.1 Ionising Radiation:

Ionisation may be simply defined as any process by which an atom or molecule gains an electric charge by the removal of an electron. Any radiation which is capable of causing this effect is known as ionising radiation. These are not to be confused with non-ionising radiations such as that produced by lasers, UV-lights, mobile phones and microwave ovens.

Ionising radiations emitted from radioactive atoms or produced by devices such as x-ray sets include:

- alpha (α) particles
- beta (β) particles
- positrons (β+)
- gamma (γ) rays
- x-rays
- neutrons

These are the only directly ionising radiations which will be of concern in a medical environment.

Alpha (α) particles

Alpha (α) particles are identical with helium nuclei, having two protons and two neutrons. Alpha particles are usually emitted by heavy radioactive atoms such as uranium and radium. Being large and relatively slow, they quickly dissipate their energy by colliding with the atoms of the material through which they travel causing ionisation to take place. Alpha particles thus have very little power of penetration and are stopped completely by a thin sheet of paper, the outer layer of human skin, or a few centimetres of air. Alpha emitters are most damaging when incorporated into the body, and are not normally used

unless securely sealed. However, there is an increasing interest in their use as therapeutic agents when they are directed specifically to the target cells.

Beta (β) particles

Beta (β) particles are high speed electrons emitted from the nuclei of radioactive atoms. Being light weight, and emitted with a speed approaching that of light, beta particles have greater penetrating ability than alpha particles of the same energy, but still will be stopped by a few millimetres of aluminium, a centimetre or so of human tissue or a few metres of air, dependent on their energy. Beta emitters are also most hazardous when ingested, but can also be hazardous, externally, especially to the cornea. Beta emitters are often administered as therapeutic agents. Beta particles do not have a distinct energy spectrum, they have a have an energy range, and therefore require an energy-dependant radiation detector in order to make a measurement. As such, a non-pressurised ion chamber instrument with a window that is capable of being opened is required to make such measurements.

Positrons (β+)

Positrons (β+) have the same mass as an electron but carry a positive charge instead of a negative charge. They have the same properties as beta particles however they eventually combine with an electron which results in the emission of 2 gamma rays. Radioactive substances which emit positrons are used in positron emission tomography (PET scans).

Gamma (γ) rays

Gamma (γ) rays are electromagnetic radiations of the same family as visible light, and travel at the same speed. They have a high penetrating power and can pass through several hundreds of metres of air or many centimetres of dense materials such as iron or lead. Gamma emitters are hazardous internally and externally, although less damaging than the particle sources.

X-rays

X-rays are physically identical to gamma rays and differ only in their means of production, which is usually by means of electrons striking a dense material as occurs in a common diagnostic x-ray machine.

Neutrons

Neutrons are subatomic particles with no net electric charge and a mass slightly larger than that of a proton. They can be used to measure the concentrations of elements (a technique known as neutron activation analysis) and can be a safety concern in certain radiotherapy treatments when the high energy x-rays can produce neutrons in the shielding material.

2.2 Radiation Units and Quantities:

Energy (eV)

The energy of particles or rays is commonly expressed in electron volts (eV). An electron volt is the energy acquired by an electron when accelerated by a potential difference of one volt. Since this is a very small amount of energy, we usually talk in terms of keV and MeV, i.e. Kilo- or mega- electron volts.

Exposure (C/Kg)

This unit measures the amount of ionisation produced in air by a given radiation source. It is measured in coulombs per kilogram of air at normal temperature and pressure and is directly related to the number of radioactive particles or gamma rays per unit area incident on a given body of mass. Exposure is easily and accurately measured.

Absorbed Dose (gray, Gy)

This unit measures the amount of energy deposited per unit mass of material by ionising radiation. One gray is the amount of radiation which will deposit one Joule per kilogram of energy in a specified material. The gray is a very large unit and most radiation dose, outside of radiation therapeutic doses, are likely to lie in the milligray (mGy) or microgray (µGy) regions. Note that the tissue or material involved must also be specified along with the absorbed dose.

For example, a chest x-ray gives about 200 µGy to the chest wall, while a radiotherapy treatment may involve 60 Gy (300,000 times as much as the chest x-ray).

Equivalent Dose (sievert, Sv)

This unit is a measure of the biological effect produced, for equal energy absorption, by different types of radiation. The relation between equivalent dose and absorbed dose is given by:

$$\text{Equivalent dose} = \text{absorbed dose} \times W_R$$

where W_R, the radiation weighting factor, is dependent on the type of radiation. For most radiation encountered in the hospital environment W_R is nearly equal to 1, so that equivalent dose often is numerically equal to absorbed dose. The sievert is again a rather large unit and most equivalent doses will be in the millisievert (mSv) and microsievert (µSv) range.

Effective Dose (sievert, Sv)

When a number of tissues or organs are irradiated to different absorbed doses, the biological effect cannot be described simply by equivalent dose, as different organs have varying sensitivities to radiation. In this case, effective dose is used, and is calculated as the sum of the equivalent dose to each irradiated organ multiplied by what is called the tissue weighting factor W_T. That is:

$$\text{Effective dose} = \Sigma_{\text{all irradiated organs equivalent dose}} \times W_T$$

The table below list the tissue weighting factors for various radio-sensitive tissues in the body:

Organs	Tissue weighting factors (W_T)
	ICRP103 2007
Gonads	0.08
Red Bone Marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Breasts	0.12
Bladder	0.04
Liver	0.04
Oesophagus	0.04
Thyroid	0.04
Skin	0.01
Bone surface	0.01
Salivary glands	0.01
Brain	0.01
Remainder of body	0.12
Total	**1.00**

Table 1

Activity (becquerel, Bq)

The radioactivity of a given radioactive source is measured in terms of the number of radioactive disintegrations per second occurring in that source. The unit of radioactivity is the becquerel (Bq) which is the activity of a source giving rise to 1 disintegration per second. Each disintegration is associated with the emission of ionising radiation. The becquerel is a very small unit, and the usual activities encountered in hospitals are in the kilobecquerel (kBq) megabecquerel (MBq) or gigabecquerel (GBq) range. The specific activity is the activity of a sample divided by its mass (Bq/g). The activity concentration is the activity of a sample divided by its volume (Bq/m^3 or Bq/mL).

Half Life

The half-life of a radioactive substance is the time taken for the substance to reach half of its original activity; that is for the disintegration rate to reduce to half its original value. This is known as the *physical half-life*, in contrast to the *biological half-life* of a material which

refers to the time taken for half an administered substance to be excreted by the body, this value having nothing to do with radiation.

The *effective half-life* (T_{eff}) is a term used to describe the amount of time taken for the body to remove half of the original introduced activity utilising both the physical (T_p) and biological (T_{bio}) half lives, and is given by the relationship:

$$T_{eff}^{-1} = T_p^{-1} + T_{bio}^{-1}$$

OR

$$T_{eff} = \frac{T_P \times T_{bio}}{T_P + T_{bio}}$$

2.3 Sources of radiation exposure (including background):

There are a number of possible situations:

- exposure may be experienced in the workplace (occupational exposure), by members
- of the public (general exposure), or by patients (medical exposure). Only occupational
- and general exposures are limited by regulations.
- the nature of the exposure may be intentional or accidental.

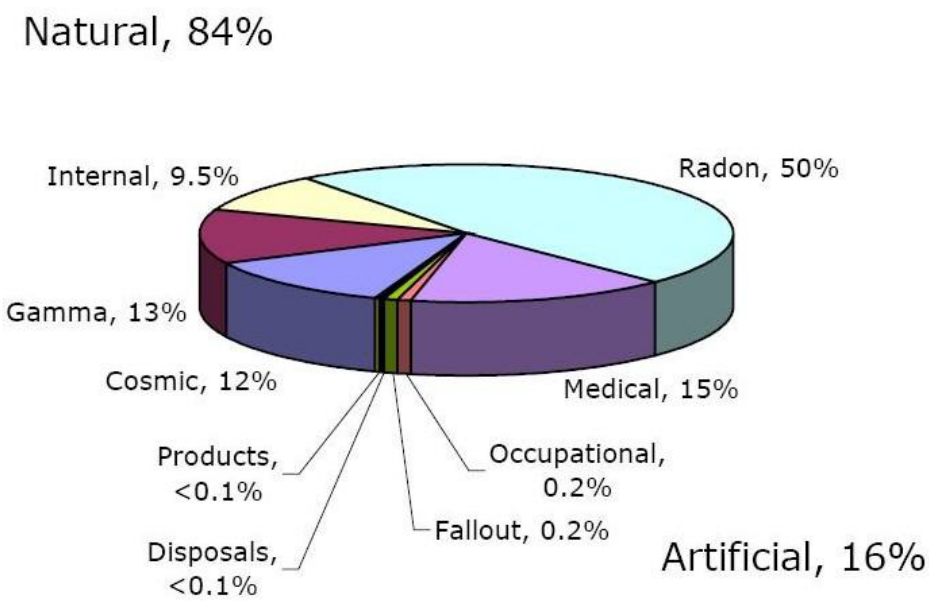
The majority of the average annual radiation dose to the population is from natural sources of radiation.

In Australia, the background radiation dose equivalent is of the order of 2-2.5 mSv. The sources of this radiation are various (see Fig. 2.1), but the greatest component is natural radon, which arises from the decay of trace amounts of uranium in the ground. Urban areas in Australia have generally low radon levels, but in some parts of the world such as Cornwall in the UK, radon levels may be very high.

Cosmic radiation arises mainly from the sun, and increases quickly with altitude above sea level, since the earth's atmosphere is a natural radiation shield. Latitude is also important: radiation levels increase as the poles are approached.

Radiation from food and drink is, in the southern hemisphere, entirely natural, and thus practically impossible to reduce.

Medical sources are the greatest man-made component of background.



Source: NRPB (UK) 2005
(Note: The section labelled "Gamma" is due to naturally occurring terrestrial sources, such as granite, mineral sands or other radioactive materials in the soil)

Fig. 1 - Average Annual Radiation Dose to the Population

2.4 Risks associated with radiation exposure

Evaluation of the risks involved due to exposure to ionising radiation is a very complex problem. Most estimates have been extrapolated from data obtained on groups of persons receiving relatively high doses (such as the victims of the Hiroshima and Nagasaki atomic bombs). These estimates assume a linear dose effect relationship down to zero dose. For example, the risks in Table 2 below represent the overall fatal cancer risk to the whole population (ref. ICRP 103).

Tissue or Organ Irradiated	Risk per mGy	
Active bone marrow (Leukaemia)	3.8 x 10-6	1 in 260,000
Bladder	2.3 x 10-6	1 in 430,000
Bone surface	0.5 x 10-6	1 in 2,000,000
Lung	11.3 x 10-6	1 in 88,000
Breast (females)	6.2 x 10-6	1 in 160,000
Thyroid	1.0 x 10-6	1 in 1,000,000
Skin	4 x 10-6	1 in 250,000
Stomach	7.7 x 10-6	1 in 130,000
Colon	4.9 x 10-6	1 in 200,000
Oesophagus	1.5 x 10-6	1 in 660,000
Liver	3.0 x 10-6	1 in 330,000
Ovary (females)	0.9 x 10-6	1 in 1,100,000
Total cancer risk	**56 x 10-6**	**1 in 18,000**
Severe hereditary disorders (all generations)	1.9 x 10-6	1 in 525,000
Baseline cancer mortality from all other causes	0.15 – 0.25	1 in 4 – 1 in 6
Table 2 - Risks due to radiation assuming no threshold dose		

In order to put the above risk in perspective, risks of death of 1 in 1 million from various causes are compared in Table 3, but the public perception of risk can be very different.

Scenario	Cause of Death
Travelling 100 miles by car	Accident
Travelling 1000 miles by jet aircraft	Accident
Travelling 10 miles by bicycle	Accident
Travelling 6 minutes by canoe	Accident
Smoking 1.4 cigarettes	Cancer, heart disease
Eating 40 tablespoons of peanut butter	Liver cancer
Spending 1 hour in a coal mine	Pneumoconiosis
Living for 150 years within 20 miles of a nuclear power plant	Radiation-induced cancer
Table 3 Comparative risks associated with a risk of death of 1 in 1 million	

2.5 Radiation and Pregnancy

Ionising radiation is potentially harmful to the foetus. The risks however, for diagnostic and occupational levels of radiation exposure, are very small. The risks due to ionising radiation are summarised in Table 4.

Time after Conception	Effect	Risk	Normal Incidence In Live-Born
First 2 weeks	No deterministic or stochastic effects in live-born child	Nil	-
3rd to 8th weeks	Potential for malformation of organs	Threshold 100-200 mGy	1 in 17
8th to 25th weeks	Potential for reduction in IQ	Threshold 100 mGy	1 in 200
4th week to end of pregnancy	Cancer in childhood or adult life	1 in 17,000 per mGy	2-3 in 1000

Table 4 Effects Following Irradiation in utero (Taken from ICRP 60, 1991 and ICRP 84, 2000)

For the vast majority of diagnostic procedures, organ malformation and mental retardation due to radiation exposure are not expected, as the foetal dose delivered is well below the threshold levels for these effects.

Deliberate irradiation of pregnant and potentially pregnant female patients naturally requires some caution. The general rule is to ask the patient if she is, or could be, pregnant. If the patient is pregnant, she should be counselled as to the possible risks before the study is commenced. The procedure is described fully in SESLHDPR/535 (for radiotherapy), SESLHDPR/551 (for diagnostic and interventional radiotherapy) and SESLHDPR/552 (for nuclear medicine).

Exposure of the embryo or foetus of a patient who is subsequently found to be pregnant often creates unnecessary worry in the mind of the patient or her medical practitioner. In fact, the risk of radiation exposure, even at relatively large levels, is very small compared to the normal risks of pregnancy (see Table 3 above).

All cases of **accidental or unintentional** irradiation of a foetus or embryo must, for the sake of all concerned, be referred to the Radiation Safety Officer for investigation and assessment.

Female staff members working with radiation or radioactive material are sometimes concerned as to the well-being of their foetus if they fall pregnant and continue to work in the same situation until the pregnancy is recognised. When a pregnancy is confirmed, arrangements should be made to ensure that the woman works only under such conditions that the foetus is accorded the same protection as for a member of the public, ie. at the rate of 1 mSv per year. Staff working in areas where radiation is used routinely may request special radiation exposure monitoring whilst they remain at work (Contact the Radiation Safety Officer for details).

Staff members who are concerned about their own circumstances are welcome to contact the Radiation Safety Officer for further information.

3. Objectives of radiation protection

Radiation effects are divided into two groups:

- stochastic effects
- deterministic effects

These terms are rather academic, but are not too difficult to understand.

Stochastic Effects

In stochastic effects, the probability (but not the severity) of occurrence is related to the magnitude of the dose, without threshold. An example is cancer induction. A small dose will give you a small probability of getting cancer, and a larger dose, a larger probability - however the severity of the cancer is the same in both cases. Hereditary effects are also stochastic. It is highly probable that small doses of radiation carry zero risk (or could even be beneficial). However, for protection purposes, a conservative approach is taken.

Deterministic Effects

With deterministic effects, there is a threshold below which the effect does not occur. Beyond this threshold the severity of the effect is related to the dose. An example is a radiation skin burn - a small dose will not produce a burn, a very large dose will, and the larger the dose the worse the burn.

The objective of radiation protection is to prevent harmful deterministic effects, and to limit the occurrence of stochastic effects to acceptable levels.

This objective is achieved by a philosophy based on

- justification for any radiation exposure
- optimisation of any dose to the lowest possible levels ("As Low as Reasonably Achievable" - the ALARA principle)
- setting limits to the equivalent dose (not including natural or medical radiation) which can be received in any year by workers and the general public.

Dose limits are treated as just that, and not as a permitted maximum.

For patients, the lowest radiation dose which provides the diagnostic information or therapeutic outcome should always be aimed for.

The occupational dose limits are set by the International Commission on Radiological Protection and have been incorporated into the NSW Radiation Control Regulation.

4. The uses of radiation and radioactivity within the LHD

The LHD is comprised of several facilities that use ionising radiation, ranging from comprehensive teaching hospitals to dental facilities with one x-ray machine. The facilities may use any combination of the following:

4.1 Radiation therapy/oncology

This process involves using either high powered linear accelerators, or high activity radioactive sources (brachytherapy) to treat disease, most often cancer. Departments utilising radiation therapy will quite often also use computed tomography (CT) and/or planar x-ray devices for treatment planning and alignment purposes.

4.2 Nuclear medicine

This process uses unsealed radioactive sources for diagnostic scintigraphy or therapeutic purposes. Diagnostic studies typically require the patient to ingest or be injected with a

radioactive substance and the radiation is detected by a radiation detector outside the body such as a gamma camera or PET scanner. One therapeutic procedure that is often performed by nuclear medicine departments is the treatment of thyroid disease using unsealed radioiodine.

4.3 Diagnostic radiology

This process involves using radiation generating apparatus for the purposes of providing a diagnostic image of a patient. Such equipment typically utilises plane x-ray machines, CT machines, fluoroscopy machines and dental x-ray machines to produce an internal image of a patient. Other diagnostic procedures such as bone mineral densitometry and mammography also utilise x-rays. Other radiological procedures include magnetic resonance imaging and ultrasonography but these modalities do not use ionising radiation and do not present a radiation hazard to the patient or to the staff.

4.4 Laboratories

Some laboratories use unsealed radioactive substances in radioimmunoassays or as tracers when studying how different materials move through biological or other systems. These techniques may be used for research or form part of routine pathology tests undertaken by SEALS.

4.5 Sample Irradiation

This process uses high activity sealed sources or high-powered linear accelerators to provide extremely large doses of radiation to a sample. The process that most utilises irradiation is the one for blood sterilisation which inhibits lymphocyte division to eliminate the risk of rejection of the blood products. Such a Blood Irradiator is used by SEALS Blood Bank.

5. DOCUMENTATION

None.

6. AUDIT

Not Required.

7. REFERENCES

[1] ICRP Publication 103 The 2007 Recommendations of the International Commission on Radiological Protection

8. VERSION AND APPROVAL HISTORY

Date	Version	Version and approval notes
Aug 2010	Draft	Richard Smart, Area Radiation Safety Officer in conjunction with the Area Radiation Safety Committee
Nov 2010	Revised draft	Richard Smart, revised in accordance with comments received
February 2011	0	Approved by Combined Clinical Council
April 2011	1	Richard Smart, revised to include radiation and pregnancy considerations
December 2015	2	Periodic Review
November 2016	2	Review and updates approved by Executive Sponsor
December 2019	3	Review and updates approved by Executive Sponsor
21 July 2023	3.1	Minor review. Approved by Executive Sponsor