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CODE OF SAFE PRACTICE FOR THE USE OF
UNSEALED RADIOACTIVE MATERIALS

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APPENDICES:

1. INTRODUCTION

1.1 This Code of Safe Practice covers the general use of unsealed radioactive materials. More specific uses are covered by the following other NRL Codes of Safe Practice: C3 (Nuclear Medicine), C11 (Treatment of cats with I-131).

1.2 For the purpose of this Code, any radioactive material is considered to be **unsealed** if it can be readily dispensed from its container in a dispersible form (liquid, soluble solid, powder, or gas) and it is intended to be used in this form. Any reference to radioactive material in this Code assumes it is unsealed.

1.3 Whenever compliance with a requirement in this document is required as a condition to a *licence* under the Radiation Protection Act 1965, the word "**shall**" is used in the clause. The word "**should**" indicates a practice that is recommended but not mandatory. Clauses without either of these words are for information and do not imply obligation for compliance with this Code.

1.4 If a word is printed in *italics* this means that the term is to be interpreted in the strict sense as defined in the Glossary.

1.5 This 1996 revision makes changes based on the recommendations of the International Commission on Radiological Protection (ICRP). While this Code uses the SI units of measurement exclusively, it is appreciated that some literature and instruments still use the superseded units. Appendix 8 sets out the relationship between the units, and conversion factors.

2. RADIATION PROTECTION LEGISLATION

The legislation under which this Code is written, is:

The Radiation Protection Act 1965
The Radiation Protection Regulations 1982.

The Act and Regulations may be amended or replaced before this Code is next revised. If so then references to legislation in the Code **shall** be deemed to refer to the current legislation. In the event of contradiction between the Code and revised legislation, the requirements of the legislation **shall** be paramount.

It must be noted that this Code deals with the requirements of radiation protection legislation only. Other legislation covering occupational safety, protection of the environment, local body planning and other issues may overlap with the radiation protection legislation in some respects, and may impose additional requirements. Compliance with this Code in no way implies that all or any of these other requirements have been satisfied. (An exception is in the transport of radioactive materials requirements, where the IAEA Regulations effectively meet all the requirements of the transport of dangerous goods measures under the Transport Act.)

2.1 Licences

2.1.1 The Radiation Protection Act 1965 does not permit any person to use radioactive materials above an exempt activity (Column O in Appendix 2) for any purpose unless he or she holds a *licence* under the Act for that purpose, or is acting on the instructions or under the supervision of a person holding such a *licence*.

2.1.2 The interpretation of the “supervision or instructions” phrase varies depending on the hazard of the radioactive material involved. If hazardous activities are being used, the ability for a *licensee* to delegate responsibility may be restricted by a *licence* condition. Generally, for typical tracer uses of radiochemicals, *licensees* are able to delegate liberally, by supervision and by instruction. Such delegation can cover absences. However, even if the hazard is slight, if a *licensee* is to be absent for more than six months alternative licensing arrangements **should** be made.

2.1.3 *Licences* under the Act are issued by the National Radiation Laboratory (NRL) and are subject to conditions, written on each *licence* form. Compliance with a Code of Safe Practice issued by NRL is a common condition. In order to define the responsibility of the *licensee*, a condition on the *licence* may state what practices are permitted and at what location. When there is more than one *licensee* at an establishment, a condition will state whether the *licensee* is a *principal licensee*, or is subordinate to a *principal licensee* (see 2.5 below).

2.1.4 *Licences* for work covered by this Code may be issued for the purposes Education, Pathology Tests, and Scientific Practice.

2.1.5 A *licence* will usually restrict the activity of any radioactive material that may be ordered and handled by the *licensee*. The activities permitted depend on the degree of protection given by the laboratory facilities, and on the experience and training of the *licensee*. The laboratory will be classified as A, B or C according to the scheme given in Section 5, and the limits are given in Appendix 2. Note that this Appendix lists the most common radionuclides only. Limits for others can be obtained from NRL.

2.1.6 If the radioactive materials are to be used outside a laboratory area (eg, agricultural or environmental studies) then a detailed safety assessment **shall** be provided with the *licence* application (or subsequently prior to the placing of the order for radioactive material). Any uncontrolled release of radioactive material into the environment **shall** comply with the requirements for disposal of radioactive waste (Section 12).

2.1.7 Any *licence* application is assessed on the basis of the qualifications and experience of the applicant, taking into account the advice of the Radiation Protection Advisory Council when necessary.

2.1.8 Each *licensee* **shall** be responsible for all radioactive material purchased under his or her *licence*, unless it is transferred to another *licensee* (see Section 2.7).

2.2 Licences for education

2.2.1 If the *licence* is for the use of radioactive materials for the education of undergraduate tertiary students, then the activity that may be handled by the students **shall** be restricted to the A limit in Appendix 2.

2.2.2 If the *licence* is for the use of radioactive materials for the education of primary or secondary students, then the activity that may be handled by the students **shall** be restricted to the O limit in Appendix 2 (except that a licensed teacher may use greater activities for demonstrations).

2.3 Licences for pathology tests

2.3.1 If the use is limited to in vitro medical pathology tests using tracer amounts of radioactive material, then the *licence* may be held by a laboratory technologist. In this case the *licence* will contain a condition prohibiting administration of radioactive material to humans.

2.3.2 If very low activity in vivo pathology tests such as Schillings or carbon dioxide breath tests with C-14 are to be used as well, these can be covered by a *licence* for Pathology Tests but the *licence* can only be held by a medical specialist, generally a pathologist. If any higher activity diagnostic procedures are used, then the use requires a *licence* for Medical Diagnosis, and is subject to the Code of Safe Practice for the Use of Unsealed Radioactive Materials in Medical Diagnosis, Therapy, and Research, NRL C3.

2.4 Licences for scientific practice

Licences for Scientific Practice are issued for most uses of radioactive materials for tracer investigations in non-medical laboratories.

2.5 Legal responsibilities; multiple licences

2.5.1 Whenever more than one *licensee* is employed in a given area, Regulation 9(3) of the Radiation Protection Regulations 1982, requires that the owner of the radioactive material either appoints one as *principal licensee*, or clearly defines the respective areas of responsibility of the individual *licensees*.

2.5.2 When two or more *licensees* share a common facility such as a radiochemistry laboratory, then one will be designated as *principal licensee*. This designation may be decided by the *licensees* or by NRL. Where the responsibility is ambiguous (such as disposal of accumulated waste) then this will default to the *principal licensee*. When a *licence* is either a *principal licence* or is subordinate to a *principal licence* this will be stated in a condition on the *licence*.

2.5.3 At each establishment, checking of some radioactive materials, confirmation of standing orders and other information in the NRL database is required on an annual basis. Where there are multiple *licensees*, the *principal licensee* **shall** do this at the time of annual *licence* renewal.

2.6 Ordering of radioactive materials

2.6.1 Where an order is made through an agent authorised by NRL (whose importations receive automatic customs clearance):

(a) Orders **shall** be placed on the approved order forms available from the agent. All sections of the form must be completed.

(b) If the order is signed by a person currently licensed under the Radiation Protection Act 1965 and the *licence* number is included on the form, the agent has been authorised by NRL to place the order on his principals immediately. A copy of the order is sent to NRL who have the power to refuse consent for the importation. If the order form cannot be completed (eg, if there is no *licensee*) then the order **shall** be referred to NRL for approval before placement.

(c) If the order is required to be repeated on a regular basis, a standing order may be placed with an authorised agent. The order **shall** be clearly marked "Standing Order" and give the frequency of deliveries.

2.6.2 When an order is placed with an agent not authorised by NRL:

(a) The following details **shall** be supplied to NRL:

The name and address of the firm supplying the material
The name and address of the person ordering the material
Name and number of *licensee* if there is one

Full details of the material (radionuclide, activity, etc).

(b) On receipt of these details, NRL will, after checking that the material will be delivered to a suitably licensed person, (if the activity is not below the limit exempt from licensing) issue an

"Authorisation to Import Radioactive Material".

Two copies of this will be forwarded to the person placing the order. The material may now be ordered. The original of the certificate must be given to the Customs Department for clearance of the material on arrival.

2.6.3 In the absence of the *licensee*, another person may sign an order only if authorisation in writing to do this has been given to the Director, NRL, by the *licensee*.

2.7 Transfer of radioactive material from one licensee to another

2.7.1 Transfer of radioactive material from one *licensee* to another in a different establishment is not permitted unless prior approval is obtained from NRL (Radiation Protection Act 1965).

2.7.2 If a similar activity of the same radionuclide is to be transferred on a continuing basis, approval is only required before the first transfer, provided all transfers are reported in accordance with Section 13.2.

2.8 NRL inspections

2.8.1 A data base of all radioactive materials imported by each *licensee* is maintained at NRL. All *licensees* who are ordering radioactive materials regularly will be visited from time to time to review radiation safety.

2.8.2 The frequency of visits will depend upon the activities being ordered and the degree of hazard.

3. RADIATION PROTECTION PRINCIPLES

3.1 Basic principles

The New Zealand radiation protection legislation is based on the following three principles, most recently set down by the International Commission on Radiological Protection in Publication 60 (ICRP, 1991a):

(a) No practice **shall** be adopted unless its introduction produces a positive net benefit to the exposed individuals or to society. (Justification of the practice.)

(b) In relation to a particular practice, the magnitude of individual radiation doses, the number of people exposed, and the likelihood of incurring exposure **shall** be kept **a**s **l**ow **a**s **r**easonably **a**chievable (ALARA), economic and social factors being taken into account.

(c) The dose or potential dose to individuals **shall** not exceed the limits set by the Commission. (Individual dose limits.)

3.2 Justification of a practice

3.2.1 The justification of the use of any radioactive materials **shall** take into account the benefits from the procedure, the relative merits of alternative modalities, and the risks entailed in the use of radioactive material.

3.3 Optimisation of protection

3.3.1 Any facilities for handling unsealed radioactive materials **shall** be designed so as to maintain as low as reasonably achievable the undesired exposure of individuals from radiation, and the risk of any failure in equipment or procedure that could result in the undesired exposure of individuals.

3.3.2 Any practice using unsealed radioactive materials **shall** use the minimum activity of the least hazardous radionuclide that will achieve the desired result.

3.4 Individual dose limits

For the purpose of this Code of Safe Practice the radiation dose limits are those specified by ICRP 60. Every *licensee* **shall** ensure that no person exposed to radioactive material under his or her control exceeds these limits. The principal limits are:

3.4.1 Limits for persons exposed to radiation as a normal condition of employment:

(a) an *effective dose* of 20 mSv per year averaged over any five year period and 50 mSv in any one year;

(b) an *equivalent dose* of 500 mSv to the skin at the nominal depth of 7 mg/cm^2 averaged over 1 cm^2, regardless of the total area exposed, in any one year;

(c) an *equivalent dose* of 150 mSv to the lens of either eye in any one year;

(d) an *equivalent dose* of 500 mSv to the hands and feet in any one year;

(e) for women who declare themselves pregnant, an *equivalent dose* of 2 mSv at the surface of the abdomen over the remainder of the pregnancy. The intake of any radioactive materials over the remainder of the pregnancy **shall** not exceed one-twentieth part of the annual limit on intake (ALI).

If the limit (a) is not to be exceeded, then in any year no worker **shall** take into the body (by ingestion, inhalation, or through a wound) more than one ALI of any radioactive material. In the case of more than one radionuclide, the sum of the fractions of an ALI of each **shall** be less than one (see Appendix 1).

3.4.2 Limits for members of the public:

(a) an *effective dose* of 1 mSv in any one year;

(b) an *equivalent dose* to the lens of the eye of 15 mSv in any one year;

(c) an *equivalent dose* to the skin of 50 mSv over any 1 cm^2, regardless of the area exposed, in any one year.

If the limit (a) is not to be exceeded, then in any year no member of the public **shall** take into the body more than one twentieth of an ALI of any radioactive material. In the case of more than one radionuclide, the sum of the fractions of an ALI of each **shall** be less than one twentieth.

3.4.3 The terms "dose" or "*radiation dose*" are commonly used. In the context of dose limits, the precisely defined terms "*effective dose*" and "*equivalent dose*" are required. (See Part A of the Glossary.)

4. RADIATION HAZARD CONTROL

4.1 External radiation hazards

4.1.1 Whenever a radionuclide emits gamma rays, x-rays or high energy beta particles there is a potential external radiation hazard. The skin and eyes are at greatest risk when the radiation is weakly penetrating (betas of energy between 50 keV and 5 MeV, and gammas or x-rays of energy less than 15 keV). The whole body may be at risk in a field of strongly penetrating gammas.

4.1.2 The amount of penetrating radiation is measured using the quantity *ambient dose equivalent* $H^*(10)$ and non-penetrating radiation using the quantity *directional dose equivalent* $H'(0.07)$. (See the Glossary for full definitions.) For simplicity, when the context is clear, the term *radiation dose* will be used to refer to the amount of external radiation. The *radiation dose* rate at 1 m from some commonly used radionuclides is given in Appendix 3.

4.1.3 The *radiation dose* rates in any accessible working area **shall** be kept to a minimum and in any case the following maximum rates **should** not be exceeded:

(a) At the working position in front of a laboratory workbench the *radiation dose* rate **should** be less than 10 μSv/h.

(b) On the surface of a container to be held frequently in the hand the *radiation dose* rate **should** be less than 250 μSv/h.

(c) At the eyes the *radiation dose* rate **should** be less than 75 μSv/h.

4.1.4 The *radiation dose* rate in any area next to a laboratory accessible by people not working with radiation **should** be less than 0.5 μSv/h. This may be relaxed by a factor of up to 10 if the area is not occupied all the time.

4.1.5 Three means of providing protection from external radiation are:

(a) Shielding

Gamma and x-ray radiation is most effectively shielded using high atomic number materials, most commonly lead. The thickness of lead that reduces the *radiation dose* rate to one tenth (the tenth value layer, TVL) is given in Appendix 3 for commonly used radionuclides.

Pure beta emitters **should** be shielded using low atomic number materials such as perspex or wood products. (Perspex, although expensive, is commonly used if a transparent shield is needed.) High energy betas generate bremsstrahlung in lead shielding and this is much more penetrating than the original betas. The thickness of perspex required to stop all of the beta radiation from commonly used materials is given in Appendix 3.

The closer to the source the shielding is, the smaller the area of shielding that is required. It is preferable to shield the container rather than the whole work area.

(b) Distance

If the volume of a radiation source is small (a "point source") then doubling the distance from it reduces the *radiation dose* rate by a factor of 4 (the "inverse square law"). Conversely, reducing the distance from 100 mm to 1 mm (a factor of 100) increases the *radiation dose* rate by a factor of 10 000. The dose rate to the fingers can be reduced very significantly by the use of even quite short forceps.

Whenever practical in a significant radiation field, equipment or operating procedures **should** be used to maximise the distance from the radiation source. Unshielded containers **should** be held in tongs.

(c) Time

The risk from an exposure to radiation is proportional to the total absorbed dose and is independent of the dose rate (within reasonable limits). Therefore any reduction in the time of exposure results in a corresponding reduction in risk.

All procedures that involve exposure to radiation **shall** be carried out as quickly as practical. The time spent near a radiation source **shall** be kept to a practical minimum. Any direct dispensing or handling procedure **shall** be designed to keep to a practical minimum the time that the source is exposed. A new procedure **should** be practised with non-radioactive materials first.

4.2 Internal radiation hazards

4.2.1 If an unsealed radioactive material is absorbed internally, the degree of hazard depends on the types of radiation emitted, the organs where the material localises, the biological residence time in the body, and the physical half-life of the radionuclide. Once a radioactive material is within the body, the greatest hazard is from non-penetrating radiation (alphas and low-energy betas), because this is all absorbed within the local tissue. However, most gamma-emitting radionuclides also emit non-penetrating radiation in the form of low energy x-rays and Auger electrons.

4.2.2 The annual limit on intake (ALI) of commonly used radionuclides is given in Appendix 1. This is the ingested or inhaled activity that in an average adult will ultimately give an *effective dose* of 20 mSv.

4.2.3 The most common routes of internal absorption that must be protected against are:

(a) Ingestion

This usually occurs when an article becomes contaminated and is passed to the mouth. The risk of this is reduced if strict hygiene rules are observed.

There **shall** be no food or cosmetics (hand cream, etc) allowed in any area where radioactive materials are handled. Mouth pipetting **shall** not be permitted. Procedures **shall** be designed to contain the radioactive material and minimise the chance of uncontrolled spread (see Section 4.4).

(b) Inhalation

There is a risk of inhalation of radioactive material whenever the material is handled in open containers and is in a form that may vaporise, nebulise, or be released as a gas. Any radioactive material in dry powdery form can pose an inhalation hazard.

In these cases, if the activity handled is greater than that given in Column A in Appendix 2, then the procedure **shall** be performed in a contained workstation (eg, a glove box) or a fume cupboard. (See Section 5.2.8.)

(c) Through broken skin

Radioactive materials can be absorbed into the bloodstream through broken skin.

Any cuts or broken skin on the hands **shall** be covered with a waterproof dressing and disposable gloves **shall** be worn.

4.3 Hazards from contamination of skin and eyes

Most radioactive materials and particularly high energy beta emitters give a high local dose to the skin or eyes if they come in contact. Many materials are either very difficult to remove or are absorbed through the skin.

Whenever unsealed radioactive materials are handled and there is a possibility of spillage or splashing, disposable gloves, a laboratory coat or gown, and where appropriate, protective glasses, **shall** be worn.

4.4 Controlled Areas and restricted access

4.4.1 Any laboratory or work area where radioactive materials of greater activity than in Column B of Appendix 2 are dispensed **shall** be designated a Controlled Area as required by Regulation 21 of the Radiation Protection Regulations 1982 by the *licensee* responsible for the materials. If activities greater than Column A are handled frequently, particularly in a busy laboratory, then the *licensee* **should** consider declaring the laboratory a Controlled Area.

4.4.2 The entrance to a Controlled Area **shall** display a warning sign indicating that entry is prohibited without the permission of the *licensee* or authorised agent. The sign needs to comply with Section 5 of the Second Schedule to the Radiation Protection Regulations 1982.

4.4.3 There **shall** be a written protocol produced by the *licensee* detailing under what circumstances entry is permitted, and the procedure for gaining permission. It **shall** also detail any special rules that must be observed within the Controlled Area. It **shall** be readily available to anyone needing to enter the Controlled Area.

4.5 Pregnant women working with radiation

4.5.1 The limit for the ingestion or inhalation of radioactive material by a pregnant woman (who is exposed to radiation as part of normal employment) is one twentieth of an ALI (see Section 3.4.1(e)). If good laboratory practice is followed, there will be no routine intake of radioactive material. The only possibility of intake is in the event of a spillage. Therefore, generally, a pregnant worker **should** not perform procedures in which more than the A limit activity is manipulated in a single container. A pregnant worker **should** not be required to clean up a spillage of more than the A limit of activity.

4.5.2 The limit for external radiation exposure is an *equivalent dose* of 2 mSv to the surface of the abdomen (3.4.1(e)). If the person is continuously monitored, it will be clear from the previous readings whether any measures are required to restrict routine external exposure. If the person is not required to be continuously monitored, the exposure to this level is unlikely, and extra precautions may not be necessary. NRL **should** be contacted for advice concerning individual situations.

4.6 Limits on activities that may be handled in laboratories

4.6.1 Laboratories where unsealed radioactive materials are handled are classified as A, B or C (see the following Section). The activity of material that may be handled in each is restricted to the limits given in Appendix 2. The derivation of these limits is described briefly in Appendix 9 (see also NRL 1996/1 (Robertson, 1996a)).

4.6.2 The limits for each nuclide are derived by taking the minimum ALI, rounding it to the nearest power of 10, and multiplying it by 10, 100, and 1000, to get the A, B, and C limits respectively.

4.6.3 If alpha emitting radioactive material is in liquid form, or otherwise has a negligible inhalation hazard, then the A, B, and C limits are to be multiplied by 100.

5. DESIGN OF FACILITIES AND EQUIPMENT REQUIREMENTS

5.1 Class A laboratory design

5.1.1 Any laboratory where radioactive materials above the O limit (Appendix 2) are handled **shall** have the facilities normally required in a chemistry laboratory for the safe handling of hazardous liquids.

5.1.2 Work surfaces, floor coverings, and other accessible surfaces such as seats **shall** be impermeable and easily decontaminated. Floor coverings **should** be non-slip.

5.1.3 Any work bench where radioactive materials, that emit external radiation exceeding the limits of Section 4.1.3, are handled, **should** be equipped with a shielded work station. This **should** be provided with a screen of lead glass or lead perspex for gamma radiation, or perspex or other clear plastic for beta radiation. There **shall** be sufficient room behind the shielding for the use of remote handling tongs if necessary. The shielding **should** be sufficient to attenuate the radiation in accordance with Section 4.1.3. The bench top **should** have equivalent shielding to protect the operator’s lower body.

5.2 Class B laboratory design

5.2.1 A Class B laboratory **shall** comply with all the requirements for a Class A laboratory.

5.2.2 The laboratory, or that part of it used for radioactive materials, **should** be designated a Controlled Area at the *licensee’s* discretion (see Section 4.4).

5.2.3 The laboratory **shall** be of sufficient size to allow ease of use. Separate work surfaces **shall** be provided for handling radioactive materials and doing bookwork.

5.2.4 If the laboratory for handling radioactive material is part of a larger laboratory, this area **shall** be segregated from the rest of the work area, with no through traffic.

5.2.5 Separate facilities **shall** be provided for washing utensils used for the handling of radioactive materials. A separate sink **shall** be used for the disposal of liquid radioactive waste.

5.2.6 Hand washing facilities **should** be provided that permit turning on of the water without using the hands.

5.2.7 The wall behind the work bench may need added shielding in order to comply with Section 4.1.4, depending on the building materials used and the occupancy on the other side.

5.2.8 A fume cupboard **shall** be installed if required because of an inhalation hazard (Section 4.2.3(b)). The construction and siting of any new or refurbished fume cupboards, and the associated fans and ducting, **shall** comply with New Zealand Standard 7203 (SNZ, 1992). This document provides detailed advice on fume cupboards and **should** be consulted whenever an installation is planned.

If a glove box or similar contained workstation is used instead of a fume cupboard, in compliance with 4.2.3(b), its design **shall** be approved by NRL.

5.2.9 Any cupboards or enclosed storage areas that are used for holding stock radioactive materials, check sources, or waste before disposal, **should** be well shielded if any of the materials emit penetrating radiation. Since the materials will be continuously irradiating anyone working in the laboratory, the ALARA principle requires that this exposure be minimised.

5.3 Class C laboratory design

5.3.1 A Class C laboratory **shall** comply with all of the requirements for a Class B laboratory.

5.3.2 The laboratory **shall** be a Controlled Area (see Section 4.4).

5.3.3 The laboratory **shall** be a separate room used only for this purpose, with no through traffic.

5.3.4 Bench surfaces **shall** be coved against the walls and lipped at the edges. The floor covering **shall** be impermeable with welded joins and be coved against the walls for ease of decontamination.

5.3.5 Shielding **shall** be provided if the *radiation dose* rate limits in Section 4.1.3 would otherwise be exceeded in the laboratory, or the limits in Section 4.1.4 exceeded outside the laboratory.

5.3.6 If significant activities of liquid waste are to be disposed of into the sewerage system (greater than 1 ALI in any one day – see Appendix 1) in concentrations approaching the liquid disposal limit (see Appendix 5) then a disposal sink **shall** be used with a sluice-type flush. This **shall** be a separate installation used only for this purpose. The drain **should** be connected as directly as possible to the main sewer. Traps **should** be accessible for monitoring for contamination build up.

5.4 Survey instruments

A variety of instruments are used for radiation protection purposes. “Radiation dosemeter”, “dosimeter”, “survey meter”, “contamination monitor”, “geiger counter”, “ion chamber”, “scintillometer”, and variations of these terms, are among the names used for different types of these instruments, used to detect different types of radiation, for different protection purposes.

Generally, the response of instruments is used either to indicate the *radiation dose* rate, in units of µSv/h or mSv/h, to assess any external radiation hazard, or else to indicate surface contamination, in units of Bq/cm^2. These are two different concepts which must not be confused, otherwise the measurement results will be misleading. The instrument reading needs to be multiplied by a calibration factor to derive the desired quantity.

5.4.1 Survey instruments **shall** be provided:

(a) To measure surface contamination, if more than 1 ALI of any radioactive material is handled in an open container;

(b) To measure radiation dose rate if this can exceed the limits in Section 4.1.3.

5.4.2 The type of radiation survey instrument **shall** be appropriate for the form of radiation monitored:

(a) High energy gammas (> 0.05 MeV):

Most types of radiation survey meter respond satisfactorily. Examples are GM (geiger-muller) probe, scintillation probe, ion chamber. The instrument is usually calibrated using Cs-137 gammas, with a graph or table indicating if this changes with energy.

(b) Low energy gammas (< 0.05 MeV, eg, I-125):

A thin-crystal scintillation probe specially designed for low energy gammas **should** be used. This is much more sensitive than other types of probe.

(c) High energy betas (> .04 MeV) and alphas (> 3 MeV):

A probe with a thin window **shall** be used. The external radiation dose rate is not a hazard, so the instrument will be used for contamination detection and **should** have an audible rate indicator. There are instruments available that are specialised for this (eg, proportional counters with foil windows). However, these can be misleading if used in the presence of gamma radiation, and a pancake GM probe is more suitable in this case.

(d) Low energy betas (< 0.04 MeV) and alphas (< 3 MeV):

These cannot be detected using the normal type of radiation survey meter. In this case contamination **shall** be monitored using wipe tests. See Section 9.1.3.

5.4.3 The reading that a survey meter gives depends on:

(a) The units that the scale reads in (counts per minute, mR/h, etc);

(b) The type and energy of radiation being measured;

(c) The type of probe attached to the meter (if it is possible to use different probes).

In many cases the reading on the meter will need to be multiplied by a calibration factor to give the quantity required.

Some survey meters have selectable scales for different radionuclides. While these are convenient to use, it is of course vital to use the correct range setting. This is an important consideration when several different radionuclides are used in the same laboratory.

5.4.4 Any radiation survey instrument required under Section 5.4.1 **shall** be calibrated at regular intervals, using methods approved by NRL, so that the *radiation dose* rate of external radiation may be measured in µSv/h and/or contamination levels may be measured in Bq/cm^2.

If the instrument's display options include count rate (counts per minute or second) the calibration factor **should** be in terms of the count rate.

5.4.5 A wall-mounted area monitor is not generally necessary in a radioisotope laboratory. However, it does serve the purpose of letting the operator know if an unshielded container of radioactive material is left exposed. The regular survey meter placed on a shelf, switched on, and using a mains adapter power supply may be used to serve this purpose.

5.4.6 In some GM-tube instruments the tube or the associated circuitry may saturate, or even paralyse, when exposed to high dose rates. Such instruments must be used with caution as a low or zero reading is possible when the instrument is exposed to a high dose rate. Always switch the instrument on in an area where the dose rate is known to be low.

5.5 Emergency equipment

5.5.1 Every Class C laboratory **shall** have ready access to an emergency kit located in a well-marked place.

5.5.2 The emergency kit **should** contain:

(i) Radiation survey meter

(ii) Protective clothing
Gown(s)
Impermeable gloves
Disposable overshoes

(iii) Personnel decontamination equipment
Mild soap or chelating detergent
Sponge
Iodide or iodate tablets (if appropriate)

(iv) Surface decontamination equipment
Bucket
Brush
Towels or absorbent pads
Forceps or tongs
Decontaminating agent
Plastic bags, sealing tape.

(v) Warning sign to prevent entry.

(vi) Any other items to cater for circumstances unique to the laboratory or the nuclides or materials being used.

5.5.3 The emergency kit **shall** be checked at least annually to ensure that everything is present and in good condition.

6. LABORATORY PROCEDURES

6.1 Manual of Standard Procedures

Whenever activities of radioactive material greater than the A limit are handled, a Manual of Standard Procedures **should** be drawn up. This **should** contain standard methods for all procedures that are performed routinely. In particular it **should** include:

(a) A protocol for the receipt of material shipments including opening, testing, recording, etc.

(b) A protocol for management and disposal of radioactive waste.

(c) The procedure to be followed in case of an emergency (see Section 7).

6.2 Good laboratory practice

6.2.1 All staff employed to use radioactive materials **shall** be fully trained in the principles of radiation safety.

6.2.2 All new procedures **should** be practised first with non-radioactive materials to ensure speed and efficiency of manipulation.

6.2.3 Gowns or laboratory coats and gloves **should** always be worn in class B and C laboratories, and **shall** be worn when handling activities over the A limit (Appendix 2). Gloves **should** be changed regularly when working with highly active solutions.

6.2.4 Equipment used for handling radioactive materials **should** be segregated from that used for other laboratory procedures, and **shall** be segregated when using activities over the A limit.

6.2.5 Whenever activities over the A limit are handled in an open container, it **shall** be over a tray or lipped and coved bench of sufficient capacity to contain all of the material if spilt.

6.2.6 When unsealed radioactive materials are handled over a work bench the work surface **shall** be covered with a disposable absorbent pad to limit the spread of any spills. The ideal covering has an impermeable backing. The pad **shall** be replaced whenever there is measurable contamination on it.

6.2.7 There **shall** be no mouth-pipetting, eating, use of cosmetics, or any other hand-to-mouth activities.

6.2.8 Vials of gamma emitters **should** be handled with tongs whenever the activity of the contents is greater than the A limit, or whenever the limit in Section 4.1.3(b) is exceeded.

6.3 Removal of contamination

6.3.1 Whenever any contamination is detected on work surfaces or equipment an attempt **shall** be made to remove it as soon as practical. A suitable detergent or decontamination agent, and disposable tissues **should** be used. Protective gloves **shall** be worn.

6.3.2 In many cases it is not difficult to remove the contamination to an undetectable level and this **should** be done if possible. However, if after repeated attempts, the contamination is still above the limits given in Section 6.3.3, then the area **shall** be covered with an impermeable coating that is marked to indicate the presence of contamination underneath, until the material decays to below the limit, or the surface is renewed.

6.3.3 Limits for surface contamination (averaged over 100 cm^2):

	In B or C laboratories	Everywhere else
Alpha emitters:	3 Bq/cm^2	0.3 Bq/cm^2
Other radionuclides:	30 Bq/cm^2	3 Bq/cm^2

7. EMERGENCIES

7.1 Planning for emergencies

7.1.1 An emergency is any unplanned or accidental event that increases the hazard from radioactive materials to the point where immediate intervention is required. Examples are spills, breakages, fire, earthquakes, burglaries, etc.

7.1.2 Any person who is required to work with activities of radioactive materials above the B limit **shall** be fully trained in the procedures to be taken in the event of any emergency. The procedures **shall** be documented in the Manual of Standard Procedures (see Section 6).

7.2 Spillage of an unsealed source

7.2.1 Evacuate all uncontaminated personnel from the affected area.

7.2.2 Put on protective clothing and gloves.

7.2.3 Mark the area of the spill and restrict access.

7.2.4 Prevent spread of the material by soaking up the bulk of liquids using absorbent towels held in tongs and placing in a plastic bag.

7.2.5 Clean the area, always wiping towards the centre using a decontaminating agent if necessary.

7.2.6 Monitor the area afterwards to ensure sufficient decontamination and that all contaminated articles and towels have been appropriately disposed of. See Section 6.3 for removal of contamination.

7.2.7 If the spill is of more than 1 ALI of radioactive iodine, beware of the likely release of iodine vapour. Take iodide or iodate tablets (170 mg with water) or perchlorate if there is any likelihood of uptake. A solution of sodium thiosulphite or sodium bisulphite **should** be poured over the spill to minimise the production of iodine vapour.

7.3 Personal decontamination

7.3.1 Wash any contaminated skin areas as soon as possible with warm water, mild soap or mild chelating agent and a soft sponge, being careful not to damage the skin or spread the contamination to other areas. Rinse well, dry with absorbent paper towels, then monitor the site. Repeat if necessary until no further improvement is achieved.

7.3.2 Rinse eyes, nose, mouth, or any broken skin immediately with copious water to help prevent uptake of the material. The absorption of some materials can be reduced after ingestion by taking appropriate medication, **but only on medical advice**. Iodide or iodate tablets (170 mg with water) or perchlorate should be taken for radioiodine ingestion. Antacids will inhibit the absorption of some contaminants. In particular, the absorption of radiostrontium can be substantially reduced by administration of aluminium combined with alginates (in the form of Gaviscon granules 3 - 4 g every 6 hours for 2 days). The use of activated charcoal can also reduce uptake in the GI tract.

7.4 Fire

7.4.1 Every establishment is given a fire hazard rating by NRL in terms of the radiation toxicity and external radiation hazard of the materials at the time a *licence* is issued. The Fire Department is notified of this and they may visit each establishment to locate the hazards. Generally, radiochemical laboratories will have the lowest category of radiation hazard rating for fire fighting.

7.4.2 The hazard from the fire will probably be much greater than that of the radioactive material. Therefore fire fighting requirements **shall** have precedence over restrictions on entry to Controlled Areas.

8. ACTION IN THE EVENT OF AN OVER-EXPOSURE

8.1 Remedial action

8.1.1 For the sake of this section a radiation over-exposure is defined as a radiation exposure greater than three-tenths of the limits given in Section 3.4, or an ingestion or inhalation of more than three-tenths of an ALI of any radionuclide, during a period of not greater than 3 months.

8.1.2 If anyone suspects that a person has received a radiation over-exposure he or she **shall** immediately inform the *licensee* responsible for the radioactive material involved, or, if unable to do so, the Director of NRL.

8.1.3 Any *licensee* who has become aware that a person may have received an over-exposure to radiation from radioactive material for which he or she is responsible **shall** immediately investigate the circumstances and take all reasonable steps to ensure that there is no continuing risk of over limit exposure to any person.

8.2 Notifications

8.2.1 As soon as is practicable after becoming aware of the over-exposure, the *licensee* **shall** notify the Director of NRL. If the exposure is an acute exposure over the limits of Section 3.4 then the notification **shall** be within 24 hours of discovery.

8.2.2 Within one week of the over-exposure, the *licensee* **shall** provide a written report of the circumstances of the over-exposure and measures taken to prevent recurrence to the Director NRL.

9. MONITORING

9.1 Radiation surveys

9.1.1 Up to Class A Activities: If only activities of less than 1 ALI of any radioactive material will be handled at any one time, then good laboratory practice is generally sufficient to ensure a minimal hazard and so routine monitoring of radiation levels is not mandatory. When greater activities are used then a suitable survey instrument must be kept on hand (Section 5.4.1) to monitor the clean up in case of a spill, and **shall** be used routinely each week or after each use whichever is less frequent to check for contamination.

9.1.2 Over Class A Activities: All surfaces and areas where unsealed radioactive materials are handled **shall** be surveyed after each use. When several people are sharing the same laboratory facilities, the *principal licensee* **shall** designate one individual responsible for routine monitoring.

9.1.3 When the radioactive material cannot be detected using a conventional survey meter (alphas < 3 MeV or betas < 0.04 MeV), the transferable contamination **shall** be monitored by wiping the suspect surface with a piece of absorbent paper (eg, filter paper) and subsequently counting the "wipe" using a liquid scintillant. The proportion of the contamination removed by the wipe can be increased by moistening the paper with a solvent. In the absence of direct measurements, it **should** not be assumed that more than 10% of the activity has been removed.

9.2 Personal monitoring

9.2.1 Personal radiation monitors **shall** be worn by anyone routinely working with gamma or high energy beta emitting nuclides of activities exceeding those listed in Column B of Appendix 2. Routine monitoring may be desirable in some situations where lower activities are used. This can be checked by a one-off measurement.

9.2.2 Film or TLD monitors cannot detect alphas or low energy betas (eg, H-3, C-14, S-35, and other nuclides for which no gamma radiation is listed in Appendix 1) and **should** not be worn if these are the only radioactive materials being used.

9.2.3 When personal radiation monitoring is used, this **shall** be of a type and using a service approved by NRL.

9.2.4 If the personal monitoring service is not provided by NRL, records of the radiation doses measured **shall** be forwarded to NRL as requested (see Section 13.3).

9.2.5 Staff handling activities greater than 50 MBq of I-125 or I-131 solution in open containers **shall** have a thyroid check after each occasion or once a week, whichever is less frequent. The check can be performed using any radiation monitor. A scintillation detector is the most sensitive but most Geiger tube detectors have adequate sensitivity. If any thyroid uptake is detected, it **should** be measured with a detector calibrated (in terms of activity in the thyroid gland) on a suitable neck phantom and used in a reproducible geometry. NRL **shall** be notified of any measurement indicating an uptake greater than 10 kBq (Section 13.3.2).

9.2.6 If significant activities of high-energy beta emitting nuclides (eg, P-32) are handled then the main hazard is to the fingers. If it appears that the *equivalent dose* to the skin may exceed three-tenths of the limit (Section 3.4.1), then finger monitors **shall** be worn. For information on this contact NRL.

10. TRANSPORT

10.1 General requirements and classification of packages

10.1.1 Transport of radioactive material into, through, and within New Zealand is required to comply with the IAEA Transport Regulations (IAEA, 1990). All radioactive materials imported into New Zealand will normally comply with these. However, if material is to be transported from one establishment to another within New Zealand it is up to the responsible *licensee* to ensure that these requirements are satisfied.

10.1.2 The types of package required for the activities of radioactive materials covered in this Code are "Excepted Packages" or "Type A Packages", depending on the activity. The limits for each are given in Appendix 4. It is unlikely that the Type A limit will be exceeded.

10.1.3 The two next sections detail some of the requirements for compliance with the IAEA Transport Regulations.

10.2 Excepted packages

10.2.1 An Excepted Package must be sufficiently robust and secure to withstand reasonable handling, and provide shielding such that the *radiation dose* rate at any point on the surface is less than 5 μSv per hour.

10.2.2 The package must contain the marking “Radioactive” on an internal surface to warn of the presence of radioactive material on opening the package.

10.2.3 If the material is being sent by commercial freight, then the shipping documents (air waybill or equivalent) must describe the contents as:

> “Radioactive Material, Excepted Package, – Limited Quantity of Material, UN2910”.

10.2.4 The outside of the package **shall** be marked “UN 2910”.

10.3 Type A packages

10.3.1 The requirements for Type A packages are quite detailed and are not covered fully here. However, if the package in which the material first arrived in the country is kept, and has not been damaged or deformed during opening, it may comply. The packaging must be opened and reassembled carefully to maintain the integrity of all its parts. In particular this includes any absorbent material required to satisfy requirements for radioactive liquid.

10.3.2 The original package will have labels attached indicating “Type A” and “Radioactive Material, Type A Package, UN 2915”. These should be left, or replaced if damaged, as they will still be valid. Two Category I, II or III labels must be affixed to opposite sides of the package. Which category depends on the *radiation dose* rate at the surface and at 1 metre from the surface as follows:

Maximum dose rate	At surface	1 m from surface
Category I	5 μSv/h	-
Category II	500 μSv/h	10 μSv/h
Category III	2000 μSv/h	100 μSv/h

If the *radiation dose* rate has changed from the original consignment, new labels will be required. The labels **shall** show the radionuclide, its activity in becquerel units and the Transport Index. The Transport Index is determined by taking the maximum *radiation dose* rate at any point 1 metre from the surface of the package in μSv/h and dividing by 10 (ie, the dose rate in mrem/h).

10.3.3 If air freight is to be used, a Shipper's Declaration for Dangerous Goods (blank forms are normally available from airline freight offices) **shall** be completed in accordance with the IATA Dangerous Goods Regulations. It will be reasonably clear how to fill this in from the certificate received with the original shipment. However, if there are difficulties NRL may be contacted. The Air Waybill **shall** state "Dangerous Goods as per attached Shipper's Declaration" for the goods description.

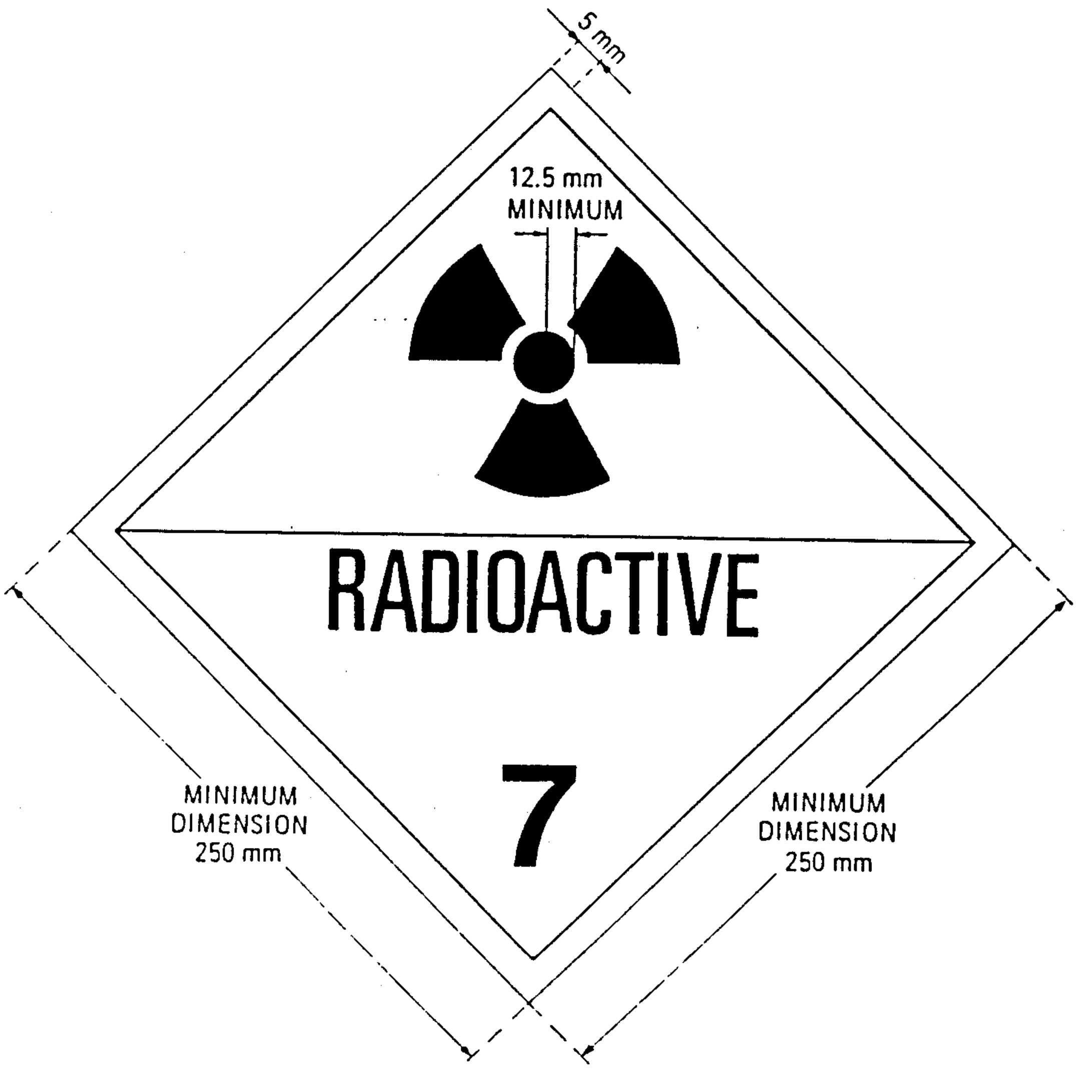
10.3.4 For road transport, a "Road/Rail/Marine Shipper's Declaration for Dangerous Goods – Class 7 Radioactive Material" (available from NRL) **shall** be included with the transport documents. For road transport in a private vehicle, this declaration **shall** be carried in the cab of the vehicle.

10.3.5 Both the airfreight and roadfreight forms require the shipper to sign a declaration that the packaging, labelling, documentation and other details comply with all applicable regulations. The person signing this declaration is then legally responsible if the shipment does not comply and there are adverse consequences.

10.4 Vehicle placarding

Any vehicle carrying radioactive materials which require a dangerous goods label (that is, all Type A and Type B packages) must be placarded. The IAEA Regulations specify that the placards be placed according to international practice, that is, at the rear and both sides of the vehicle. New Zealand law allows an alternative placement in line with standard dangerous goods placarding in New Zealand, that is, at the front and the rear of the vehicle.

The placards **shall** be at least 250 millimetres square, and be of the design reproduced below. The upper half of the diamond shall be yellow, and the lower half white.



11. STORAGE

11.1 Security

11.1.1 Radioactive materials **shall** be stored in a secure area to minimise risk of loss, theft, or damage by fire.

11.1.2 If the storage area is remote from the usual work location and the activity of the materials stored is greater than the O limit, it **shall** be locked and be accessible only to persons authorised by the *licensee* responsible for the materials.

11.2 Radiation safety

11.2.1 The external *radiation dose* rate (see Section 4.1.2) in any continuously occupied accessible area near stored radioactive material **shall** be no more than 10 μSv/h. If the outside of the storage room is accessible to non-radiation workers the dose rate at the wall **shall** be less than 0.5 μSv/h. These limits may be increased by up to a factor of 10 if the areas are less than fully occupied as long as the limits in Section 3.4 will not be exceeded in any individual.

11.2.2 Once a shipping package of radioactive material has been opened, it **shall** be stored in a manner designed to prevent spillage, breakage of the container, or contamination of other equipment. If gas or vapour is likely to be present, the room **should** be ventilated, or the material stored in a fume cupboard.

11.2.3 The *licensee* responsible **shall** have an inventory of all the stored radioactive material where the activity in an individual container or package exceeds Column A of Appendix 2, in case of an emergency such as fire. The inventory **shall** be kept at a different location from the stored material. (See Section 13.1.2.)

11.3 Signs

11.3.1 A prominent warning sign **shall** indicate any site where radioactive materials are stored. This **shall** comply with the requirements of the Second Schedule to the Radiation Protection Regulations.

11.3.2 There **shall** be a label on the door of any refrigerator or freezer in which radioactive materials are stored. No foodstuffs **shall** be kept in the same refrigerator or freezer.

11.3.3 If the materials are kept within a large walk-in store room, the shelf area where they are located **shall** be clearly labelled. If activities greater than in column A, Appendix 2 are to be stored then the outside door of the store room **should** also be labelled.

11.3.4 The container in which radioactive material is stored **shall** be clearly labelled with the following:

- The trefoil sign;
- The name of the radionuclide;
- The activity, and the reference date for the activity;
- The name of the *licensee* responsible.

Radioactive materials stored in transport packaging labelled to comply with the IAEA Transport Regulations shall be deemed to meet this requirement, if a subsidiary label shows the name of the *licensee* responsible.

12. WASTE DISPOSAL

12.1 General principles

12.1.1 Any disposal of radioactive material into the environment **shall** comply with the principles of Section 3.1. In this case that means:

(a) Justification: Radioactive material **shall** not be disposed of unless this is the safest practical option (in terms of risk from radiation exposure) compared to storage, selling, re-exporting, etc.

(b) ALARA: The total activity and the activity concentration of radioactive waste **shall** be as low as reasonably achievable.

(c) Limits: Any disposal of radioactive waste **shall** not exceed the limits given in Appendix 5.

12.1.2 The derivation of the limits is described in NRL 1996/1 (Robertson, 1996a). Observance of these limits will ensure that no waste is disposed of unless it has an activity or concentration below the exempt activity or concentration specified in the IAEA Basic Safety Standards (IAEA, 1994). (Disposal of radioactive waste generally in New Zealand is described in NRL 1996/2 (Robertson, 1996b).)

12.1.3 Any uncontrolled dispersal of radioactive material into the environment **shall** comply with the requirements of this Section irrespective of whether it is due to disposal of waste or for any other purpose.

12.1.4 No package that has contained radioactive material **shall** be disposed of or used for any other purpose unless all warning and other labels indicating that the package may have contained radioactive material have been obliterated.

12.2 Solid waste

12.2.1 The Manual of Standard Procedures (see Section 6) **should** specify the method for the disposal of each type of solid waste (contaminated disposable gloves, paper towels, syringes, etc) so that there is minimal likelihood of contaminated waste being disposed of inappropriately.

12.2.2 Short half-life waste **should** be stored in a safe place to allow decay to near background levels, then discarded with other laboratory waste.

12.3 Liquid waste

12.3.1 Disposal of radioactive liquids **shall** be restricted to a sewerage system where this means a system that treats or dilutes domestic and trade sewage to an acceptable pollutant level before release to the environment. Any other liquid disposal system is not acceptable.

12.3.2 The limits for liquid disposal are given in Appendix 5.

(a) The concentration “at sewer” refers to the total activity disposed of in a day by the institution, divided by the total daily sewage outflow.

(b) The concentration “at sink” refers to the liquid entering the disposal point (sink, sluice drain) at the time of tipping.

12.3.3 For the purpose of 12.3.2 if sewage outflow information is not available, it can be assumed that the daily outflow from a hospital is 1000 litres per bed. At other establishments it can be assumed that the daily sewage outflow is 100 litres per full time worker.

12.3.4 Radioactive liquid **shall** always be tipped slowly into a sink or sluice with the water running (but not so that it can splash). This practice will minimise the activity concentration in the drain in case there is a tendency for the material to bind to it.

12.3.5 If the radioactive liquid has a short half-life it **should** be stored safely in a suitable sealed container to decay to near background level before disposal. Because of the risk of spillage, depending on the storage and disposal facilities it may be safer to dispose of liquid radioactive waste immediately. The *licensee* **shall** take this into consideration when deciding which practice to follow.

12.4 Gaseous waste

12.4.1 Gaseous waste **shall** not be released to the atmosphere except from a stack complying with the requirements of NZ 7203 (NZS 1992).

12.4.2 The concentration **shall** not exceed the limit shown in Appendix 5, averaged over a single discharge provided the maximum concentration during the discharge is less than 100 times the average.

12.5 Uranium and thorium wastes

Before uncontrolled disposal of uranium and thorium compounds, they must be mixed with other waste to reduce the concentration to less than 1 Bq/g if they are in a dry dusty state. If there is no possibility of inhalation of dust, this dilution can be relaxed to 100 Bq/g. If the waste is soluble in water, it can be disposed of as liquid waste if the concentration at the entry to the sewer is less than 1 kBq/l. (For these purposes, the specific alpha activity of both uranium and thorium can be taken as 25 kBq/g.)

13. RECORDS AND REPORTS

13.1 Records of radioactive materials

13.1.1 The receipt of any shipment of activity greater than Column A in Appendix 2 and the dispensing or disposal of any activity greater than this **shall** be recorded. Information recorded **shall** include the date, radionuclide, activity, and in the case of receipts, the importing agent. Records **shall** be held for 10 years.

13.1.2 An inventory **shall** be kept of all radioactive materials held in activities greater than Column A of Appendix 2. This **shall** be maintained up to date and kept at a location remote from the storage area. The approximate total activity of each radionuclide stored **should** be recorded in the inventory. It is not necessary for each individual container to be listed. The inventory is for use in hazard assessment in case of an emergency such as fire or earthquake.

13.2 Records of transfer of material to another licensee

13.2.1 The transfer of any radioactive material from the control of one *licensee* to another, such that the material is moved to facilities where the first *licensee* otherwise has no responsibility, **shall** be recorded.

13.2.2 A set of all such records **shall** be supplied to NRL whenever requested or otherwise annually (see also Section 2.7).

13.2.3 Records **shall** be held for 10 years.

13.3 Personal monitoring records and reports

13.3.1 Records **shall** be kept of all personal monitoring required by this Code (Section 9.2). Results **shall** be made available to the individuals monitored on reasonable request, and in case the monitoring service is not provided by NRL, a copy **shall** be sent to NRL as soon as available.

13.3.2 If any thyroid uptake measurement indicates a thyroid burden of more than 10 kBq of radioiodine then this **shall** be reported to NRL within 1 week of the measurement.

APPENDICES

APPENDIX 1. DATA FOR COMMON NUCLIDES

Radio-nuclide	T½	Eβmax (MeV)	%	Eγ (MeV)	%	ALI
H-3	12.3y	0.0186	100			480 MBq
C-14	5730y	0.156	100			35 MBq
P-32	14.3d	1.709	100			6.3 MBq
P-33	24.4d	0.248	100			8.3 MBq
S-35	87.4d	0.167	100			15 MBq
Ca-45	163d	0.252	100			7.4 MBq
Cr-51	27.7d			0.32	9	530 MBq
Co-57	271d			0.014	9	21 MBq
				0.122	87	
				0.136	11	
Co-58	70.8d	0.475	15	0.811	99	10 MBq
Ga-67	3.26d			0.09	41	71 MBq
				0.185	24	
				0.300	17	
Se-75	120d			0.136	59	7.7 MBq
				0.265	59	
Sr-89	50.5d	1.463	100			2.7 MBq
Y-90	2.67d	2.274	100			7.4 MBq
Mo-99	2.75d	0.454	18	0.740	14	17 MBq
		1.232	80	0.141	84	
Tc-99m	6.02h			0.141	89	690 MBq
In-111	2.83d			0.171	91	65 MBq
				0.245	94	
I-123	13.2h			0.027	86	95 MBq
				0.159	83	
I-125	60.1d			0.035	7	1.3 MBq
				≈0.030	≈140	
I-131	8.04d	0.606	90	0.364	82	910 kBq
Xe-133	5.24d	0.346	99	0.081	37	
				≈0.033	≈46	
Au-198	2.69d	0.961	99	0.412	95	20 MBq
Tl-201	3.04d			0.167	10	210 MBq
				≈0.075	≈95	
Th-nat	$1.4x10^{10}$y					480 Bq
U-nat	$4.47x10^{9}$y					2.7 kBq

APPENDIX 2. LABORATORY LIMITS

Radionuclide	O limit	Laboratory limits		
		A limit	B limit	C limit
H-3	1 GBq	10 GBq	100 GBq	1 TBq
C-14	10 MBq	1 GBq	10 GBq	100 GBq
P-32	30 kBq	100 MBq	1 GBq	10 GBq
P-33	30 MBq	100 MBq	1 GBq	10 GBq
S-35	30 MBq	100 MBq	1 GBq	10 GBq
Ca-45	3 MBq	100 MBq	1 GBq	10 GBq
Cr-51	3 MBq	10 GBq	100 GBq	1 TBq
Co-57	3 MBq	100 MBq	1 GBq	10 GBq
Co-58	1 MBq	100 MBq	1 GBq	10 GBq
Ga-67	300 kBq	1 GBq	10 GBq	100 GBq
Se-75	1 MBq	100 MBq	1 GBq	10 GBq
Sr-89	30 kBq	10 MBq	100 MBq	1 GBq
Y-90	100 kBq	100 MBq	1 GBq	10 GBq
Mo-99	300 kBq	100 MBq	1 GBq	10 GBq
Tc-99m	100 MBq	10 GBq	100 GBq	1 TBq
In-111	3 MBq	1 GBq	10 GBq	100 GBq
I-123	30 MBq	1 GBq	10 GBq	100 GBq
I-125	3 MBq	10 MBq	100 MBq	1 GBq
I-131	100 kBq	10 MBq	100 MBq	1 GBq
Xe-133	3 MBq	10 GBq	100 GBq	1 TBq
Au-198	1 MBq	100 MBq	1 GBq	10 GBq
Tl-201	3 MBq	1 GBq	10 GBq	100 GBq
Th-nat	3 kBq	10 kBq	100 kBq	1 MBq
U-nat	10 kBq	10 kBq	100 kBq	1 MBq

APPENDIX 3. RADIATION EXPOSURE DATA

Radio-nuclide	Ambient dose equivalent rate ($H^*(10)$) at 1 m μSv h^{-1} MBq^{-1} (1)	Directional dose equivalent rate (H'(0.07)) at 1 m μSv h^{-1} MBq^{-1} (2)	μSv h^{-1} per $Bq.cm^{-2}$ skin contamina-tion (3)	γ attenuation 1st TVL, mm Pb	Max. range of β particles in perspex, mm
H-3	-	-	-	-	0.007
C-14	-	-	0.3	-	<1
P-32	-	5.9	2.4	-	8.2
P-33			0.9		<1
S-35			0.3		<1
Ca-45			0.9		
Cr-51	0.0054	0.0055		7.1	-
Co-57	0.020	0.028	0.08	≈0.7	-
Co-58	0.15	0.17	0.3	28	1.6
Ga-67	0.026	0.026	0.3	5.3	-
Se-75	0.067	0.063	0.1	5.1	-
Sr-89	-	5.7		-	6.8
Y-90	-	6.3	2.4	-	11
Mo-99	0.034	4.3	2.1	20	5.6
Tc-99m	0.021	0.024	0.2	0.9	-
In-111	0.082	0.088	0.4	2.5	-
I-123	0.054	0.058	0.4	1.2	-
I-125	0.033	0.039		≈0.06	-
I-131	0.064	0.066	1.7	11	2.3
Xe-133	0.016	0.017		≤0.7	1.0
Au-198	0.068	4.5	2.1	12	4.1
Tl-201	0.017	0.016	0.25	≤0.9	-
Th-nat					
U-nat					

(1) $H^*(10)$ includes contributions from all gammas and x-rays with energy greater than 20 keV.

(2) H'(0.07) includes all photons greater than 10 keV and electrons with maximum energy greater than 1 MeV. It is assumed that electrons of less energy will be absorbed within the container. Note: The relationship between air kerma and directional dose equivalent is taken from Wagner et al, 1985. No account is taken of attenuation by absorption in the solution or container walls. Therefore in a practical situation, for radionuclides with low energy photon emissions (eg, ^{125}I) or beta emitters the true values of $H^*(10)$ and H'(0.07) may be considerably less than these values.

(3) From Faw, 1992.

APPENDIX 4. ACTIVITY LIMITS FOR TRANSPORT PACKAGES (from IAEA Safety Series TS-R-1)

Radionuclide	Excepted Packages*	Type A Packages
H-3(compounds)	4 GBq	40 TBq
C-14	300 MBq	3 TBq
P-32	50 MBq	500 GBq
P-33	100 MBq	1 TBq
S-35	300 MBq	3 TBq
Ca-45	100 MBq	1 TBq
Cr-51	3 GBq	30 TBq
Co-57	1 GBq	10 TBq
Co-58	100 MBq	1 TBq
Ga-67	300 MBq	3 TBq
Se-75	300 MBq	3 TBq
Sr-89	60 MBq	600 GBq
Y-90	30 MBq	300 GBq
Mo-99	60 MBq	600 GBq
Tc-99m	400 MBq	4 TBq
In-111	300 MBq	3 TBq
I-123	300 MBq	3 TBq
I-125	300 MBq	3 TBq
I-131	70 MBq	700 GBq
Xe-133	10 GBq	10 TBq
Au-198	60 MBq	600 GBq
Tl-201	400 MBq	4 GBq
Th-nat	unlimited	unlimited
U-nat	unlimited	unlimited

* This is for materials in the liquid or gaseous form. If the material is in solid form the limit is increased by a factor of 10.

APPENDIX 5. WASTE DISPOSAL LIMITS

Radio-nuclide	Waste limits					
	Uncontrolled		Liquid		Gas	Burn
	activity (Bq)	conc. (Bq/g)	at sink (Bq/l)	at sewer* (Bq/l)	(Bq/l)	(Bq/g)
H-3	1 GBq	1 MBq/g	100 TBq/l	1 GBq/l	1 MBq/l	1 kBq/g
C-14	10 MBq	10 kBq/g	1 TBq/l	10 MBq/l	10 kBq/l	10 Bq/g
P-32	100 kBq	1 kBq/g	100 GBq/l	1 MBq/l	1 kBq/l	1 Bq/g
P-33	100 MBq	100 kBq/g	10 TBq/l	100 MBq/l	100 kBq/l	100 Bq/g
S-35	100 MBq	100 kBq/g	10 TBq/l	100 MBq/l	100 kBq/l	100 Bq/g
Ca-45	10 MBq	10 kBq/g	1 TBq/l	10 MBq/l	10 kBq/l	10 Bq/g
Cr-51	10 MBq	1 kBq/g	100 GBq/l	1 MBq/l	1 kBq/l	1 Bq/g
Co-57	1 MBq	100 Bq/g	10 GBq/l	100 kBq/l	100 Bq/l	0.1 Bq/g
Co-58	1 MBq	10 Bq/g	1 GBq/l	10 kBq/l	10 Bq/l	0.01 Bq/g
Se-75	1 MBq	100 Bq/g	10 GBq/l	100 kBq/l	100 Bq/l	0.1 Bq/g
Sr-89	1 MBq	1 kBq/g	100 GBq/l	1 MBq/l	1 kBq/l	1 Bq/g
Y-90	100 kBq	1 kBq/g	100 GBq/l	1 MBq/l	1 kBq/l	1 Bq/g
Mo-99	1 MBq	100 Bq/g	10 GBq/l	100 kBq/l	100 Bq/l	0.1 Bq/g
Tc-99m	10 MBq	100 Bq/g	10 GBq/l	100 kBq/l	100 Bq/l	0.1 Bq/g
In-111	1 MBq	100 Bq/g	10 GBq/l	100 kBq/l	100 Bq/l	0.1 Bq/g
I-123	10 MBq	100 Bq/g	10 GBq/l	100 kBq/l	100 Bq/l	0.1 Bq/g
I-125	1 MBq	1 kBq/g	100 GBq/l	1 MBq/l	1 kBq/l	1 Bq/g
I-131	1 MBq	100 Bq/g	10 GBq/l	100 kBq/l	100 Bq/l	0.1 Bq/g
Xe-133	10 kBq	100 kBq/g	100 GBq/l			1 Bq/g
Au-198	1 MBq	100 Bq/g	10 GBq/l	100 kBq/l	100 Bq/l	0.1 Bq/g
Tl-201	1 MBq	100 Bq/g	10 GBq/l	100 kBq/l	100 Bq/l	0.1 Bq/g
Th-nat	1 kBq	1 Bq/g	100 MBq/l	1 kBq/l	1 Bq/l	0.001 Bq/g
U-nat	1 kBq	1 Bq/g	100 MBq/l	1 kBq/l	1 Bq/l	0.001 Bq/g

* This limit is to apply at the point where the total outflow from an institution enters the public sewerage system.

APPENDIX 6. FEATURES OF SOME COMMONLY USED RADIONUCLIDES

A6.1 Tritium

In Appendix 2 limiting activities are given for tritium as tritium compounds. Tritium as elemental gas has a toxicity which is lower by a very large factor than that of tritium combined in any compound. It must be noted that if compounds are synthesised from tritium gas, the safety facilities necessary for the synthesis will be dictated by the toxicity of the compound, and not the gas.

Unless the gas is known to be radiochemically pure, impurities of the order of 1% or more will be the limiting consideration. Even in the form of compounds, tritium is among the least toxic of all the radionuclides, and the activities used as radioactive tracers in many cases have hazards associated with them which are almost negligible.

For some purposes large activities of tritium are used, and in such cases the hazard cannot be discounted. The beta emission from tritium is of such low energy that it gives rise to no external radiation hazard, and makes it difficult to monitor tritium contamination. Where activities of tritium could give rise to hazardous contamination, special precautions are therefore required.

A6.2 Carbon-14 and Sulphur-35

These two nuclides emit relatively low energy beta radiation. Although their metabolism may be different, they give rise to comparable radiation hazards, and precautions to control these hazards will be similar for both nuclides.

As with tritium, use of these nuclides presents no hazard from external radiation. The main points to note about them are that, because of the relatively low beta energy, a thin end window Geiger-tube will detect only about 10% of the beta particles incident upon it, and for carbon-14, the long half-life (about 6000 years) means that contamination may build up over a long period of time, and unless effectively dealt with will remain a problem permanently.

A6.3 Phosphorous-32

This nuclide also does not emit gamma radiation, but its beta emission of maximum energy 1.7 MeV means that external radiation is an important hazard. Because of the widespread use of P-32 for molecular biology, this nuclide is the subject of Appendix 7.

A6.4 Iodine-125 and Iodine-131

The radioisotopes of iodine have been in use longer than any other artificial radionuclide, and relatively high activities are in use for a variety of purposes, mostly for applications in nuclear medicine. The metabolism of iodine involves its concentration and long retention in the thyroid gland, and because of the high concentration in the small volume of tissue comprising this organ, all radioisotopes of iodine have a relatively high toxicity.

In many chemical forms these nuclides are quite volatile, and a significant hazard to be guarded against is that of inhalation of the radioactive material in gaseous form. If the activity handled in an open container at any one time exceeds 10 MBq (the A limit) then in compliance with Section 4.2.3 this must be done in a fume hood. Because of the concentration of iodine by the thyroid gland, the entry of iodine isotopes into the body is detectable perhaps more easily than is the case for any other radionuclides. Persons routinely handling activities in excess of 50 MBq of I-125 or I-131 are required to verify that there has been no uptake of radioactive material, by external counting of the thyroid gland. (See Section 9.2.5.)

The gamma radiation emitted by I-131 and to a lesser extent by I-125 may give rise to a significant external radiation hazard from activities commonly in use, and provision of shielding and remote handling equipment may be necessary. (See Section 4.1.)

APPENDIX 7. USE OF PHOSPHOROUS-32 IN MOLECULAR BIOLOGY

Several beta emitters are used routinely for labelling molecular markers for use in genetic research and manipulation. Most of these have relatively low-energy betas (H-3, C-14, P-33, S-35, etc). These can be handled safely by using good laboratory practice to minimise the risk of the spread of contamination. However, P-32 emits betas with sufficient energy to penetrate the walls of containers and therefore presents an external hazard as well.

A7.1 External hazards

The table below shows the *radiation dose* rates from an Eppendorf tube containing 1.0 MBq of P-32 in 0.1 ml of solution. Holding the tube at the base would give the annual limit *equivalent dose* to the skin in about 6 hours. Holding the tube by the top reduces the dose rate by about one twentieth.

The dose rate at arm's length distance is much less, in the range of a few tens of mSv per hour. Even at a distance of 10 cm it would take many days of continuous exposure to reach the annual limit for the eyes.

Measurements of the radiation dose rate from 1.0 MBq of P-32 in 0.1 ml of solution in a 1.5 ml Eppendorf tube (from Ballance et al 1987)

Distance (cm)	**Dose rate** (µSv/min)
Surface	1444
10	4.67
20	1.25
30	0.58
40	0.25
50	0.17
60	0.13

A7.2 Safety measures

Activities of more than 1 MBq of P-32 **should** be handled behind a perspex screen. Any stock solution or waste **should** be held in shielded containers. Perspex is the ideal shielding material but a cheaper alternative is customwood or particle board of at least 13 mm thickness.

Avoid holding containers in the fingers any more than necessary. Hold the container at the top rather than adjacent to the contents.

Do not look into an open container with the naked eye.

To protect against skin contamination always wear gloves when handling the material, and check surfaces and equipment with a monitor after each use.

A7.3 Personal monitoring (see also Section 9.2)

Personal monitoring film

Personal monitoring films are really only useful for monitoring penetrating radiation. They will detect high energy betas but will not indicate the finger dose. Worn on the collar they would indicate the dose to the eyes. However, NRL does not recommend the use of monitoring film in this type of laboratory. The hazard being monitored is only minor compared to skin dose and ingestion, and there is a danger that a null reading (which it invariably is) gives a false impression of good work practice. It is much more effective to rely on good practice and a survey meter.

Finger dose monitors

It is possible to use TLD dosemeters attached to the fingers to monitor the skin dose. Contact NRL for further information.

APPENDIX 8. UNITS OF RADIOACTIVITY AND RADIATION DOSE

The following tables list the SI units of activity and absorbed dose, used in this revision of this Code, and the older units which they replace, together with conversion factors.

Activity

New Units	**Old Units**
becquerel (Bq)	curie (Ci)
kilobecquerel (kBq)	millicurie (mCi)
megabecquerel (Mbq)	microcurie (μCi)
gigabecquerel (GBq)	
terabecquerel (TBq)	

Conversion factors

1 Bq	=	2.7×10^{-11} Ci	=	2.7×10^{-8} mCi	=	2.7×10^{-5} μCi		
1 kBq	=	10^{3} Bq	=	2.7×10^{-8} Ci	=	2.7×10^{-5} mCi	=	0.027 μCi
1 MBq	=	10^{6} Bq	=	2.7×10^{-5} Ci	=	0.027 mCi	=	27 μCi
1 GBq	=	10^{9} Bq	=	0.027 Ci	=	27 mCi		
1 TBq	=	10^{12} Bq	=	27 Ci				

1 Ci	=	37 GBq
1 mCi	=	37 MBq
1 μCi	=	37 kBq

Approximate conversion for radiation protection purposes

1 kBq	=	0.03 μCi	1 MBq	=	30 μCi	1 GBq	=	30 mCi
3 kBq	=	0.1 μCi	3 MBq	=	100 μCi	3 GBq	=	100 mCi
10 kBq	=	0.3 μCi	10 MBq	=	300 μCi	10 GBq	=	300 mCi
30 kBq	=	1 μCi	30 MBq	=	1 mCi	30 GBq	=	1 Ci
100 kBq	=	3 μCi	100 MBq	=	3 mCi	100 GBq	=	3 Ci
300 kBq	=	10 μCi	300 MBq	=	10 mCi	300 GBq	=	10 Ci
						1 TBq	=	30 Ci
						3 TBq	=	100 Ci

Dose equivalent

New Units	**Old Units**
sievert (Sv)	rem
millisievert (mSv)	millirem (mrem)
microsievert (μSv)	

1 Sv	=	100 rem		
1 mSv	=	0.1 rem	=	100 rem
1 μSv	=	0.1 mrem		

1 rem	=	0.01 Sv	=	10 mSv
1 mrem	=	0.01 mSv	=	10 μSv

APPENDIX 9. THE DERIVATION OF LABORATORY LIMITS

The derivation of limits is described in NRL 1996/1. Briefly, it is as follows.

For each nuclide, ICRP publication 68 (ICRP, 1994) lists a “dose coefficient” in units of Sv/Bq. This is the *effective dose* that would be received for each becquerel taken into the body. Several values are given for each nuclide, for different chemical forms for ingestion, and for different chemical forms and aerodynamic diameters for inhalation. The maximum value has been identified for each nuclide and the ALI (the activity whose intake will result in an *effective dose* of 20 mSv) has been calculated. This is then the minimum, most restrictive value of the ALI.

The A, B, and C limits for each nuclide are derived by taking the minimum ALI, rounding it to the nearest power of 10, and multiplying it by 10, 100, and 1000, to get the A, B, and C limits respectively.

The limits for alpha emitting nuclides are a special case. For these nuclides the dose coefficients for inhalation are much greater (by a factor of about 100 in round figures) than for ingestion. If alpha emitting radioactive material is in liquid form, or otherwise has a negligible inhalation hazard, then the A, B, and C limits are to be multiplied by 100.

These limits are based solely on the internal radiation hazard arising from the intake of radioactive material. Previously the A limit also took into account the external radiation hazard from gamma and energetic beta radiation. This change means that for all grades of laboratory, consideration must be given to routine precautions against external radiation, regardless of the laboratory classification.

GLOSSARY

PART A: Quantities and Units

Absorbed dose: The energy imparted to matter by ionization per unit mass of irradiated material at the place of interest. The derived unit of absorbed dose is the gray, being equal to 1 joule of energy absorbed per kilogram of material irradiated.

$$1 \text{ Gy} = 1 \text{ J kg}^{-1}$$

Activity (A): The number of nuclear transformations or disintegrations occurring in a quantity of radioactive material per unit time. The SI unit of radioactivity is the becquerel (Bq) (1 disintegration per second).

Ambient dose equivalent $H^*(d)$: This is an “operational unit” of radiation dose described in ICRU 47 (ICRU, 1992) designed to provide a measurable quantity that is close to the *effective dose* (see below) when d = 10 mm. $H^*(10)$ is the quantity that should be measured when assessing the external hazard from penetrating radiation (high energy gammas). See Section 4.1.

$H^*(d)$ is defined as the *dose equivalent* at a point in a radiation field that would be produced by a corresponding aligned and expanded field, in the ICRU sphere at a depth d, on the radius opposing the direction of the aligned field.

Annual limit on intake (ALI): This is the ingested or inhaled activity that in an average adult will give a total committed *effective dose* of 20 mSv. The annual limit on intake, ALI, of commonly used radionuclides is given in Appendix 1.

Becquerel (Bq): The SI derived unit of activity being one radioactive disintegration per second of time. The relationship to the traditional special unit, the curie (Ci) is 1 Bq = 2.70 x 10^{-11} Ci.

Directional dose equivalent, H'(d): This is an “operational unit” of radiation dose described in ICRU 47 (ICRU, 1992) designed to provide a measurable quantity that is close to the *equivalent dose* to the skin (see below) when d = 0.07 mm. H'(0.07) is the quantity that should be measured when assessing the external hazard to the skin or eyes from non-penetrating radiation (high-energy betas, low-energy gammas). See Section 4.1.

H'(d) is defined as the *dose equivalent* at a point in a radiation field that would be produced by a corresponding expanded field, in the ICRU sphere at a depth d, on the radius opposing the direction of the aligned field.

Dose equivalent: The product of the *absorbed dose* at a point in tissue and a quality factor that takes into account the relative effectiveness of different types of radiation for causing damage. The unit is the *sievert* (Sv).

Effective dose: This is the sum of the *equivalent doses* in all tissues of the body from a particular exposure, each weighted according to the risk associated with that tissue. It gives an indication of the overall risk of an exposure independent of the part of the body exposed. The unit is the *sievert* (Sv). (See ICRP 1991a.)

Equivalent dose: The product of mean *absorbed dose* in a tissue or organ with a radiation weighting factor to allow for the biological effectiveness of the type of radiation. The radiation weighting factors for photons and electrons are equal to 1.0. In this case the equivalent dose is numerically the same as absorbed dose. The unit is the *sievert* (Sv). (See ICRP 1991a.)

Gray (Gy): The SI unit of absorbed dose being equal to 1 Joule per kilogram of the material being irradiated.

$$1 \text{ Gy} = 1 \text{ J kg}^{-1}$$

Doses are usually expressed in the sub-multiples 1/1000 (milli) and micro (1/1000000) of a Gray, thus mGy and µGy.

Radiation dose: This term is used in this Code to denote the *equivalent dose* or *effective dose* from external radiation as estimated by the *ambient dose equivalent* or the *directional dose equivalent* respectively. Which is meant in this Code is always clear from the type of radiation referred to.

Sievert (Sv): The SI unit of *dose equivalent*, *effective dose*, and *equivalent dose*, being equal to an *absorbed dose* of one Gray, multiplied by the appropriate weighting factor to represent the amount of risk associated with the absorbed dose.

Doses are usually expressed in the sub-multiples 1/1000 (milli) and micro (1/1000000) of a Sievert, thus mSv and μSv.

PART B: Other Terms

ALARA: In relation to a particular practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposure **shall** be kept **A**s **L**ow **A**s **R**easonably **A**chievable, economic and social factors being taken into account. The principle of optimising radiation protection. See Section 3.3.

Auger electron: A low energy electron emitted during a nuclear transformation when an atom emits an x-ray that collides with one of its own orbital electrons.

Beta radiation: Electrons emitted during the radioactive decay of atomic nuclei.

Bremsstrahlung: Photons generated when moving electrons are forced to deviate strongly in their path by the proximity of a nucleus.

Gamma radiation: Photon radiation emitted during the radioactive decay of atomic nuclei.

IAEA: International Atomic Energy Agency.

IATA: International Air Transport Association.

ICRP: International Commission on Radiological Protection.

ICRU: International Commission on Radiation Units and Measurements.

Licence, Licensee: In this Code this refers to licences issued under the Radiation Protection Act 1965, to permit the use of radioactive material or irradiating apparatus. The licence confers responsibility on the licensee for the safe use of any radioactive material or irradiating apparatus under his or her control.

Principal licensee: The licensee appointed, when there are several in overlapping areas of work, to take responsibility for radiation safety when this becomes ambiguous. See Section 2.5.

Radioactive material: Any material containing *radionuclides* with an activity concentration greater than 100 kBq per kg, and a total radioactivity greater than 3 kBq.

Radionuclide: An isotope of an element that is unstable and transforms into another, emitting radiation.

Radiation Protection Advisory Council (RPAC): A council set up by the Radiation Protection Act 1965 to advise on matters arising from the administration of the Act.

Unsealed radioactive material: A *radioactive material* in a form that allows it to be readily removed from its container and subdivided or dispersed.

X-rays: X-rays produced by radioactive materials are photons radiated during a nuclear transformation after an orbital electron has been removed and another orbital electron falls down into the vacancy emitting the difference in binding energy as a photon.

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