Office of Safety, Health & Environment

NUS Radiation Safety Manual (Ionising)

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

The purpose of the NUS Radiation Safety Manual is to ensure that a structured system is in place to address radiation safety of all staff and students having to work with radioactive material.

The manual provide guidelines for all university personnel for the safe operation of laboratories and performance of experiments involving the use of radioisotopes. The policies, rules, and procedures set forth in this manual is developed with the purpose of promoting a safe environment for the protection of University of Singapore employees, students, visitors, our community as well as NUS property. The codes of practice are also developed to be aligned with recommendations and specific provisions of local government agencies.

The guidelines should be read before radioactive work in the laboratory commences. In addition, those who plan to initiate work in the lab must be familiar with the standard practices that apply as well. It is essential that laboratory personnel maintain good, prudent laboratory work practices and precautions and have an awareness of the dangerous nature of certain radioisotopes. Development of this manual has taken into considerations the various regulations pertaining to radiation work.

1.2 EMERGENCY PHONE NUMBERS AND OSHE CONTACTS

Emergency Telephone Numbers

Ambulance/Fire	995
Police	999
Campus Security (24hrs)	x1616 (6516 1616)

University Health and Wellness Centre (UHWC)

Ms Doris Yek Lee Ling	x7333 (6517 7333)
Occupational Health Nurse	

Office of Safety, Health and Environment (OSHE)

1. OSHE

Office of Safety, Health & Environment
Alumni House, Basement
National University of Singapore
21 Lower Kent Ridge Road
Singapore 119077
Main Line: 6516 6863
Emergency Line: 6778 6304
Fax: 6774 6979
http://www.nus.edu.sg/osh/contactus.htm

2. Faculty/ Department Safety & Health Officers/Coordinators

Please refer to this URL http://www.nus.edu.sg/osh/advisory.htm

CHAPTER 2 RADIATION SAFETY PROGRAM ADMINISTRATION

2.1 Basic Principles of Radiation Protection

Radiation having a wide range of energies forms the electromagnetic spectrum, which is illustrated below. The spectrum has two major divisions: non-ionizing and ionizing radiation.

Radiation that has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to remove electrons, is referred to as "non-ionizing radiation." Examples of this kind of radiation are sound waves, visible light, and microwaves.

Radiation that falls within the ionizing radiation" range has enough energy to remove tightly bound electrons from atoms, thus creating ions. This is the type of radiation that people usually think of as 'radiation.' We take advantage of its properties to generate electric power, to kill cancer cells, and in many manufacturing processes.

The energy of the radiation shown on the electromagnetic spectrum in Table 1 increases from top to bottom as the frequency rises

Low Frequency Long Wavelength ↓ High Frequency Short Wavelength	**Type of Wave**	**Typical Source**	**Wavelength (m)**	**Frequency (Hz)**	**Typical Uses**	**Dangers of Over Exposure**
	Radio	Electronic circuits (vibrating electrons)	> 0.1	$< 3 \times 10^9$	Communications: radio, TV	(Safe unless very concentrated)
	Microwaves	Electronic circuits; cool objects	10^{-3} - 0.1	3×10^9 - 3×10^{11}	Communications: satellites, telephony, heating water, food	Burning if concentrated
	Infra-red	Electronic devices; warm objects; sun	7×10^{-7} - 10^{-3}	3×10^{11} - 4×10^{14}	'Magic eyes' in security lighting, remote control	Burning if concentrated
	Visible light	Electronic devices (LED, laser); hot objects; sun	4×10^{-7} - 7×10^{-7}	4×10^{14} - 7.5×10^{14}	Visual, photography	Burning, blindness if concentrated
	Ultra-violet	Gas discharge lamps; very hot objects; sun	10^{-8} - 4×10^{-7}	7.5×10^{14} - 3×10^{16}	Suntan lamp, making ions, making vitamin D	Sunburn, skin cancer
	X-rays	Very fast electrons hitting a metal target	10^{-11} - 10^{-8}	3×10^{16} - 3×10^{19}	Imaging defects in bones, hidden devices	Cell destruction, cell mutation, cancer
	Gamma rays	Radioactive nuclei decaying	$< 10^{-11}$	$> 3 \times 10^{19}$	Medical tracers, killing cancer cells, sterilization, imaging defects in metal	Cell destruction, cell mutation, cancer

Table 1 Electromagnetic Spectrum

2.1.1 Non-ionizing Radiation

Non-ionizing radiation is described as a series of energy waves composed of oscillating electric and magnetic fields traveling at the speed of light. Non-ionizing radiation includes the spectrum of ultraviolet (UV), visible light, infrared (IR), microwave (MW), radio frequency (RF), and extremely low frequency (ELF). Lasers commonly operate in the UV, visible, and IR frequencies. Non-ionizing radiation is found in a wide range of occupational settings and can pose a considerable health risk to potentially exposed workers if not properly controlled.

For more technical and regulatory information on the control of occupational hazards from non-ionizing radiation, please refers to NUS Non Ionising Radiation Safety Manual.

2.1.2 Ionizing Radiation

Higher frequency ultraviolet radiation begins to have enough energy to break chemical bonds. X-ray and gamma ray radiation, which are at the upper end of magnetic radiation, have very high frequency -- in the range of 100 billion Hertz -- and very short wavelengths--1 million millionth of a meter. Radiation in this range has extremely high energy. It has enough energy to strip off electrons or, in the case of very high-energy radiation, break up the nucleus of atoms.

Ionization is the process in which a charged portion of a molecule (usually an electron) is given enough energy to break away from the atom. This process results in the formation of two charged particles or ions: the molecule with a net positive charge, and the free electron with a negative charge.

Each ionization releases approximately 33 electron volts (eV) of energy. Material surrounding the atom absorbs the energy. Compared to other types of radiation that may be absorbed, ionizing radiation deposits a large amount of energy into a small area. In fact, the 33 eV from one ionization is more than enough energy to disrupt the chemical bond between two carbon atoms. All ionizing radiation is capable, directly or indirectly, of removing electrons from most molecules.

There are three main kinds of ionizing radiation:

- alpha particles, which include two protons and two neutrons;
- beta particles, which are essentially electrons; and
- gamma rays and x-rays, which are pure energy (photons).

In order for radiation safety policies, regulations and procedures to be effective, the following administrative structure is put in place.

2.2 *UNIVERSITY RADIATION SAFETY POLICY*

The policy can be downloaded via the following URL:
https://wws.nus.edu.sg/osh/nus_manuals/policies/University_Radiation_Safety_Policy.pdf

2.3 ROLES AND RESPONSIBILITIES

a. NUS Institutional Laboratory Safety Committee (ILSC)

Institutional Laboratory Safety Committee (ILSC) has been formed to serve as an advisory to review Standards and Guidance Documents related to general laboratory safety at the university level.

The ILSC is appointed by the Provost. The Terms of Reference for the ILSC are:

1. Review the SOPs, Standards and Guidance Documents at university, faculty and departmental level and recommend revisions to the Director of OSHE.

2. Serve in an advisory capacity to OSHE on all chemical, radiation and physical safety related matters pertaining to laboratories.

3. Review the NUS Chemical and Radiation Programme, as well as any audit and inspection findings conducted by OSHE or other independent parties on faculties and departments.

4. Review the NUS Chemical and Radiation Policy and recommend to the NUS President on specific action items related to the Chemical and Radiation Programme.

5. To endorse risk assessments that cannot be effectively evaluated at the departmental or faculty level, including appeals by Principal Investigators.

The Committee will be assisted by the Occupational Safety and Health Management Division of OSHE.

b. Deans and Head of Departments (HOD)

All Deans and HODs of respective lab-based faculties and departments will ensure that their respective faculty or departmental radiation SOPs, standards and guidance documents as well as components of the Radiation Programme implemented at departmental and faculty level are in order and reviewed periodically. Faculty Safety Officers and personnel appointed to assume safety responsibilities (herein called the "Departmental Safety Committee" shall be empowered by the respective Deans or HODs to coordinate the NUS Radiation Programme at the faculty and departmental level.

Respective HODs are responsible for the review of the risk assessment submissions of Principal Investigators before their submissions to the ILSC. HODs should verify, where possible, the consistency of the risk assessment submissions.

c. Principal Investigator

It is the responsibility of the respective Principal Investigators to ensure safe handling of radioactive material in his/her lab.

In performing the risk assessment, Principal Investigators will document that protocols and facilities do not jeopardize the health and well being of themselves, their employees, students, the general public, and that all personnel working in laboratories in which radioactive material are handled are familiar with the relevant local and university level SOPs and guidance documents, and are appropriately trained and informed of the risks and hazards present in the lab under his/her charge. All risk assessment submissions are to be submitted to the respective Heads of Departments (HODs)/ Deans for endorsement prior to their submissions to the ILSC.

The Principal Investigator will be accountable for the inventory of radioactive material in his/her lab. It is also the responsibility of the Principal Investigator to provide the necessary resources needed to ensure good safety practices and adequate infrastructure for the safe operation of the lab.

d. Faculty Safety Officer

The Faculty Safety Officer will review periodically radiation surveys in restricted, controlled and uncontrolled areas to determine that dose rates and amounts of contamination were at ALARA levels.

The Faculty Safety Officer will also review periodically the external radiation doses of authorized users to determine that their doses are ALARA in accordance to the current Radiation Protection Acts. The Faculty Safety Officer will report any failure to comply to the Departmental Safety Committee and OSHE.

The Faculty Safety Officer may be tasked to investigate all known instances of deviation from good ALARA practices and if possible, will determine the causes.

e. Other Employees, Students and Support Staff

All other staff members and students must comply with all university and local level SOPs, standards and guidance documents that are applicable to their area of work.

Support staff should have knowledge or be informed of the nature of work of the laboratory, and of the safety regulations and procedures of the university.

Support staff includes maintenance service personnel (internal service crew and external contractors who repair and maintain the structure, facilities and equipment) as well as domestic cleaning service providers.

f. Office of Safety, Health & Environment (OSHE)

OSHE will provide administrative support to the ILSC, maintain the University Radiation Safety Manual, manage all registration and reporting processes for the ILSC, maintain appropriate records, and serve as liaison with all faculties, departments and external agencies in the ongoing implementation of the University's Radiation Safety Programme.
OSHE will also coordinate the provision of radiation training to relevant staff through the NUS Structured Safety Training System (SSTS). OSHE will arrange periodic laboratory audits and reviews on departments and faculties. OSHE will also be the university body tasked to coordinate any incident or accident investigations as called for by the ILSC or the President.

CHAPTER 3 RADIATION SAFETY REQUIREMENTS

The following information describes the requirements for all researchers in the National University of Singapore undertaking lab-based research projects radiation work. It is the responsibility of each Principal Investigator to ensure the laboratory is in compliance.

3.1 WORK INVOLVING RADIOACTIVE MATERIAL

All Principal Investigators (PIs) who plan to use radioactive material are required to complete and submit a project risk assessment before any new research project or task is implemented; or when there are changes to that may affect the safety and health aspects of the project / task or as and when required by the University. Details of risk assessment procedures are available through the Office of Safety, Health and Environmental (OSHE) website in OSHE SOP (OSHE/SOP/U/05) "Project/task Risk Assessment" http://www.nus.edu.sg/osh/manuals/sop.htm. The Risk Assessment Form can also be downloaded from the same web site.

All risk assessment submissions for projects/tasks requiring grant funding are to be submitted to the respective Heads of Departments (HODs)/ Deans for endorsement prior to their submissions to the ILSC. PIs can only commence work after their risk assessment has been approved.

All PIs are accountable for the inventory of the radioactive material in his/her lab and are responsible for ensuring safe operation of the laboratory.

3.2 COMPLIANCE WITH REGULATIONS OF GOVERNMENTAL AGENCIES

The procurement, possession or use of radioactive material is permitted only pursuant to a Radiation License issued by the National Environment Agency (NEA). This is to control the import/export, sale, transport, possession and use of radioactive materials and irradiating apparatus. The Centre for Radiation Protection and Nuclear Science (CRPNS), National Environment Agency, is the controlling authority for the safe use of ionising and non-ionising radiation in Singapore. CRPNS administers the Radiation Protection Act and Regulations through a system of licensing and inspections.

Under the Radiation Protection Act and the Radiation Protection (Ionising Radiation) Regulations, the following licences are issued by the Centre for Radiation Protection and nuclear science:

L1 – To manufacture, possess for sale or deal in irradiating apparatus.

L2 – To manufacture, possess for sale or deal in radioactive materials.
L3 – To keep or possess an irradiating apparatus for use (other than sale).
L4 – To keep or possess radioactive materials for use (other than sale).
L5 – To use irradiating apparatus (other than sale).
L6 – To use, handle and transport radioactive materials (other than sale).
L6A – To handle and transport radioactive materials.
L7 – To import or export a consignment of irradiating apparatus.
L8 – To import or export a consignment of radioactive materials.
R1 – To register as a radiation worker.

The licence application forms may be downloaded from the NEA website at www.nea.gov.sg

Should you need further assistance, kindly contact your Faculty Safety Officer or OSHE.

A separate licence to keep or possess irradiating apparatus shall be required for each irradiating apparatus.

PI must be L5/L6 licensee. This is in line with the Regulations that the L5/L6 licensee must be a person in a supervisory position, and knowledgeable on radiation safety.

Anyone else in the lab involved in radiation work must be registered as a radiation worker (R1). Lab officer, staff and students should be the R1 licensee. The R1 radiation workers are supposed to work under the supervision of the L5/L6 licensee who in turn is obliged to instruct them on matters related to radiation safety.

An individual is considered a radiation worker if his work:
(a) involves the use or handling of any radioactive substance;
(b) involves the use or operation of any irradiating apparatus; or
(c) is required to be carried out in proximity to any irradiating apparatus or radioactive substance or both, such that he is liable to receive a dose in excess of one-tenth of the dose limit for radiation workers.

3.3 CONTROL OF RADIATION EXPOSURE AND CONTAMINATION

Exposure to ionizing radiation shall be kept as low as is reasonably achievable (ALARA).

Occupational external and internal exposure from radioactive material shall be controlled such that no individual shall receive a radiation dose in excess of the values given in the following table.

It should be noted that the exposure to natural background radiation or from other exposures received by the radiation worker as a member of the public is not taken into account.

Application	**Dose limit per year (mSv)**
Effective dose (whole body)	20
Equivalent dose in	
The lens of the eye	150
The skin	500
The hands and feet	500

3.3.1 Control of Exposure from External Sources

The three basic methods used to control external radiation exposure are:

- *Time* → Radiation dose is proportional to the time spent in the radiation field.
- *Distance* → The maximum practical distance should be maintained between any part of the person's body and the radiation source. The dose received is inversely proportional to the distance from the radiation source.
- *Shielding* → A shield in the radiation path will cause the radiation to be attenuated and also cause it to be scattered in various directions. The type of shielding used will depend on the type and energy of the radiation.

Any one method or any combination of the three methods should be used to keep personal exposure to **A**s **L**ow **A**s **R**easonably **A**chievable (**ALARA**).

3.3.2 Control of Exposure from Internal Sources

Sealed radioactive sources normally cause only external exposure of individuals to radiation, but unsealed sources can give rise to both internal as well as external irradiation. Unsealed radioactive sources can enter the body via inhalation, ingestion or dermal contact causing the internal organs to be irradiated. Some radionuclides may concentrate in certain organs, causing these organs to receive particularly high doses. Once taken up by the body, the radionuclide will be subject to biological half-life as well as the radioactive half-life.

The Radiation Protection Regulations do not specify maximum permissible body burdens or maximum permissible concentrations. Instead, the Annual Limit on

Intake (ALI) of a radionuclide for radiation workers is specified. ALI is defined as the activity of a radionuclide which, if taken alone into the human body, would irradiate the individual to the dose limit specified in the Regulations for the radiation worker. Different radionuclides have different values of ALI.

When handling unsealed radioactive sources, it is necessary to take special precautions to avoid contamination of the work area as well as prevent inhalation and ingestion of the radionuclides.

3.3.2 General Rule of Thumb

The general rules of thumb are as follows:

1. It requires a beta particles of at least 70keV to penetrate the protective layer of the skin (0.07 mm thick).

2. The average energy of a beta particle is 1/3 times the maximum energy: $E_{avg} = 1/3(E_{max})$.

3. The range of a beta particle in air is approximately 3.7m per MeV.

4. The intensity of bremsstrahlung (braking) radiation increases as the energy of the beta particle and the atomic number of the absorbing material increases. Thus, a shield consisting of low atomic number material should be used for P-32.

5. When beta particles of 1 to 2 MeV pass through light materials such as water, plexiglass, or glass, less than 1% of their energy is dissipated as bremsstrahlung.

6. The beta particles from the decay of P-32 are stopped in 0.7cm of plexiglass.

7. Lead is an excellent shield for low energy X and gamma ray emitters. The thickness of lead needed is determined by the intensity and energy of the X and gamma rays.

8. The half value layer (HVL) is the thickness of an absorber (e.g. lead) that will reduce the X and gamma ray intensity by a factor of 2.

3.4 USING RADIOISOTOPES IN ANIMALS

When radioisotopes are used in animals, the areas in which animals are kept must be posted.

Cages and pens must bear labels listing the isotopes used, the quantity and date administered, measured external radiation levels, and the name of the Principal Investigator. These cages and pens should be separated from those housing non-radioactive animals.

Ventilation should be adequate to handle the possibility of airborne activity. In some instances, this may require the use of a fume hood or self-contained, controlled environmental systems.

Procedures for disposal of animal excreta must be included in the radiation license application process. If animal excreta are mixed with bedding materials, handle in accordance with dry radioactive waste procedures.

Animal caretakers must be instructed and adequately trained by Principal Investigator with respect to general and specific handling procedures, dose levels, occupancy time limits and other special conditions. Trained research personnel should provide all the animal care-taking duties.

3.5 DETECTION AND MONITORING

Since ionizing radiations are not detected by the human senses, each project/laboratory using radioactive material must have appropriate radiation detection measurements. All detection methodologies are based on the ability of such radiation to cause ionization, directly or indirectly.

3.5.1 Portable Radiation Monitors

These are battery operated hand held meters, such as Geiger counters and scintillation counters. They are used at radiation facilities and work sites to ensure that the radiation level is within the limits specified in the Regulations, that the radioactive source has returned to its safe position or to check that contamination of surfaces has not occurred. Portable radiation monitors usually consist of a probe or detecting head and the associated electronic circuitry. The probe contains the detector – a GM tube, ionization chamber or sodium iodide crystal. Sometimes, it is fitted with a removable shield to allow measurements in mixed radiation fields. Most portable survey meters are intended for dose rate measurements, while some have integrating facilities, which enable the total dose in a given time to be recorded. Portable radiation monitors must be calibrated at periodic intervals in a radiation calibration facility.

3.5.2 Area Radiation Monitors

The prime purpose of this type of monitoring instrument is to give an indication of the external radiation levels present in an area where ionizing radiations are present, and in some cases, to sound an alarm if the level exceeds a predetermined value. Area radiation monitoring systems usually are designed to respond to gamma radiation and may use either GM tubes or ionization chambers in the detecting heads.

3.5.3 Personal Dosimeters

The purpose of personal dosimeters is to determine how much radiation a radiation worker receives in the course of his work. This is usually in the form of a Thermoluminescent Dosimeter (TLD) badge, a quartz fibre electroscope (QFE-dosimeter or a beeper.

The TLD badge consists of two Lithium Fluoride (LiF) chips mounted on a card and encased in a special holder. It is worn like a badge on the body of the radiation worker for one month. During this time, the amount of radiation which the worker received is recorded on the TLD chips. After one month, the card is send back to HSA for measurement of the amount of radiation to which the wearer has been exposed to. The used card will also be exchanged for a new one.

The TLD badge may be supplemented by the QFE dosimeter or the beeper especially for those workers involved in Non-Destructive Testing (NDT) work. The QFE dosimeter or pen dosimeter contains a quartz electroscope in a small ionization chamber. It is provided with an optical system. The advantage of this dosimeter is that it gives an immediate reading of the dose received by the wearer. It is very useful for individuals who need to enter a radiation area to do a particular job. Beepers make use of miniature GM tubes in small instruments which are carried in the pocket. They produce an audible “beep” warning sound, at a rate dependent on the radiation level. When a predetermined dose rate is exceeded, it will give a warning note which increases in frequency with dose rate.

3.5.4 Monitors for Internal Radiation Contamination

Measurements for internal contamination can be done on body excretions e.g. urine, or can be made directly on the body using a whole body counter or thyroid monitor, depending on what is being tested for.

3.6 MEDICAL SURVEILLANCE

Under the Regulations, no individual below the age of 18 can be engaged in radiation work. The applicants for L5 and L6 licence as well as R1 registration must undergo a medical examination including a full blood count to ensure that they are medically fit for radiation work.

In the event of accidental internal deposition of radioactive material, bioassay tests shall be performed as appropriate.

The action levels for bioassay measurement results are as follows:

1. Investigatory action levels: Any measurement result that exceeds 5% of the annual limit on intake (ALI) initiates an investigation to evaluate the source of the exposure and the means of improving handling techniques. All such investigations must be fully documented.

2. Administrative action levels: Any measurement result that exceeds 25% of the ALI would initiate suspension of the lab operations until satisfactory control measures are implemented.

A copy of the bioassay measurement must be submitted to OSHE within 2 weeks of receipt.

3.7 RADIATION SAFETY TRAINING REQUIREMENTS

Each Principal Investigator is responsible for providing safety training to persons using radiation sources under his or her supervision. Apart from specific radiation safety training by the individual PIs, staffs and students working with radiation are encouraged to attend the Radiation Safety Training (Ionizing) and Radiation Safety Training (Non-Ionizing) conducted by OSHE. The details of the courses are available at **www.nus.edu.sg/osh**

The following topics are recommended to be covered by the Principal Investigator before working with radioactive materials:

- Health protection problems associated with exposure to radioactive materials or radiation.
- Precautions or procedures to minimize exposure.
- Purposes and functions of protective devices employed.
- The Licensing conditions and applicable portions of the Singapore Radiation Protection Acts.
- Worker's responsibility to promptly report any condition that may lead to or cause a violation of the regulations or cause an unnecessary exposure.
- Actions to take in the event of an emergency.
- Radiation exposure reports that workers may request.

Particular attention should be given to contamination survey requirements, dosimetry requirements, necessary documentation, safety precautions/equipment, authorized radioactive material, possession limits, precautions during pregnancy and locations where radioactive materials are authorized.

The extent of the instruction shall be commensurate with the potential radiological health problems in the work area.

3.8 STORAGE OF RADIOACTIVE WASTE MATERIAL

Radioactive materials must be secured at all times. This may be accomplished by any of the following means:

1. Attending the materials
2. Maintaining materials in a designated locked freezer or cabinet
3. Locking the room in which the materials are stored

These requirements apply to all radioactive materials in the laboratory, including waste, contaminated equipment, and sealed sources. If found lost, report immediately to the respective PI and OSHE.

Radioactive materials stored in occupied areas shall be shielded in accordance with the ALARA.

Unbreakable containers are recommended for storage of radioactive liquids. Glass or fragile bottles and other breakable containers used for storage must be kept in non-breakable, leak proof secondary containers or trays capable of containing the entire volume of liquid stored in the primary container.

Radioactive gases and volatile forms of radioisotopes should be stored in a well-ventilated area, such as fume hood.

Radioisotopes and calibration sources shall be clearly labeled with the OSHE yellow sticker for radioactive waste.

3.9 TRANSPORTATION OF RADIOACTIVE MATERIALS

The transportation of radioactive materials is controlled by the Radiation Protection (Transport of Radioactive Materials) Regulations 2000. These Regulations are based on the International Atomic Energy Agency's (IAEA's) Regulations for the safe transport of radioactive materials.

Within Singapore, a license issued by CRPNS is required, to transport radioactive materials from one place to another.

Placards, with the radiation hazard logo, as specified in the Regulations, shall be placed on both sides of the vehicles whenever it is carrying radioactive material. The vehicle should never be left unguarded while parked, with radioactive materials inside.

The radiation level at any place occupied by any individual in the vehicle shall not exceed 0.02 mSv/hr, unless this individual is provided with a personal monitoring badge.

The vehicle carrying the radioactive material shall not carry any individual less than 18 years of age or any individual unconnected with the transport or use of the radioactive material.

For international transport, the radioactive source must be properly packaged and labeled. The type of packaging and labeling required would depend on the type and quantity of the radioactive material. The different types of packaging are:

- Excepted packages;
- Industrial packages;
- Type A packages;
- Type B packages which are further classified into Type B(U) or Type B(M) packages; and
- Type C packages.

Excepted packages contain low quantities of radioactive materials and surface dose rates must be less than 0.005 mSv/hr.

Industrial packages are ordinary containers used for materials of low activity. A typical industrial container is a metal drum – for radioactive wastes or ores.

Type A packages are designed to withstand ordinary conditions of transport including minor accidents. They are subject to tests which simulate routine conditions such as exposure to rain, rough handling and slight mishaps.

Type B packages are designed to withstand ordinary conditions of transport and severe accidents. Containers for Type B packages have to be subjected to mechanical, thermal and immersion tests to demonstrate their ability to withstand severe accidents.

Type C packages are designed to limit the potential doses to acceptable levels should the package be involved in a severe air accident. The contents are limited to ensure that any conceivable release under accident conditions would not exceed the appropriate regulatory limits.

The Transport Index (TI) is a number assigned to a package to provide control over radiation exposure. It is defined as the maximum radiation level at a distance of 1m from the external surface of the package, measured in units of mrem/h. If the radiation level is determined in units of mSv/h, the value determined shall be multiplied by 100.

Packages are assigned to either category I-WHITE, II-YELLOW or III-YELLOW in accordance with the following conditions as tabulated below.

Conditions		Category
Transport Index (TI)	**Maximum radiation Level At Any Point On External Surface**	
0 (including TI<0.05)	Not more than 0.005 mSv/h	I-WHITE
More than 0 but not more than 1	More than 0.005 mSv/h but not more than 0.5 mSv/h	II-YELLOW
More than 1 but not more than 10	More than 0.5 mSv/h but not more than 2 mSv/h	III-YELLOW
More than 10	More than 2 mSv/h but not more than 10 mSv/h	III-YELLOW

Where the transport index satisfies the condition for one category but the surface radiation level satisfies the condition for a different category, the package shall be assigned to the higher category of the two. Category I-WHITE is regarded as the lowest category. For example, if the TI of a package is 0.6, and the maximum radiation level on the external surface of the package is 1 mSv/h, then the package will be assigned to Category III-YELLOW.

The number of category II-YELLOW and category III-YELLOW packages stored in any one storage area, such as a transit area, terminal building, store room or assembly yard, shall be so limited that the total sum of the transport indexes in any individual group of such packages does not exceed 50. There should be a distance of at least 6m between two such groups.

3.10 RADIOACTIVE WASTE DISPOSAL

OSHE will conduct the radioactive waste disposal 3 to 4 times per years depending on demand. Specific COP covering this aspect can be found in http://www.nus.edu.sg/osh/manuals/sop.htm

CHAPTER 4 RADIATION ACCIDENTS

A radiation accident shall be considered to have occurred if:

- An unexpected, uncontrolled high level of ionizing radiation occurs as in the case of loss, by damage, of the radiation shielding of a sealed radioactive source or of irradiating apparatus;

- An individual enters a high radiation field by accident;

- There is a loss of control of unsealed radioactive material causing a spillage or leakage of the radioactive material;

- The skin or clothing of an individual becomes contaminated; or

- Radioactive material is accidentally released into the environment in excess of the discharge level permitted by the Regulations;

such that:-

- Any individual has, or could have, received an effective dose which is equal to or in excess of one fifth of the dose limit as specified in the Regulations;

- The skin or personal clothing of any radiation worker is contaminated in excess of 50 times (2.5 times for any other individual) the appropriate permitted contamination limits for skin or personal clothing as specified in the Regulations;

- Any area in the premises where work with ionizing radiation or radioactive material is conducted, is contaminated in excess of 50 times the permitted contamination limit for surfaces in such an area as specified in the Regulations; or

- Any other area is contaminated in excess of 10 times the permitted contamination limit for surfaces in low level laboratories as specified in the Regulations.

CHAPTER 5 DECONTAMINATION PROCEDURES

It is recommended that prior to commencement of experiment a survey is conducted to ensure that the work area is free of contamination from the previous group.

At the end of the experiment, it is the responsibility of all to decontaminate the work area prior to leaving the work area.

5.1 TYPES OF CONTAMINATION

Removable contamination can be readily removed using proper decontamination procedures. Removable contamination in any amount may present both an external and internal hazard because it can picked up on skin and possibly ingested.

Fixed contamination cannot be readily decontaminated. Fixed contamination generally does not present a significant hazard unless the material comes loose or is present in such large amounts that it presents an external radiation hazard.

5.2 TYPES OF SURVEYS

2 types of survey methods are

- Direct surveys, using a Geiger-Muller (GM) detector or scintillation probe, can identify gross contamination (total contamination consisting of both fixed and removable contamination) but will detect only certain isotopes.
- Wipe surveys, using “wipes” such as cotton swabs or filter papers counted on a liquid scintillation counter or gamma counter, can identify removable contamination only but will detect most isotopes used at the University. Wipe surveys are the most versatile and most sensitive method of detecting low-level removable contamination in the laboratory.

5.2.1 Performing a Meter Survey

Prior to performing any survey, clean gloves should be worn. This prevents the possibility of personal contamination or cross-contamination. Next, perform an instrument check to ensure that the survey meter is working properly.

Conduct and record the background count. Go to an area with an expected low background rate. The background rate for a GM meter should be less than 100 counts per minute while the background reading for a Na I meter should be less than 400 counts per minute. If background readings exceed these levels, investigate the area for unknown sources of radiation or detector contamination. Do not use the survey meter if it does not register a background count.

Do not cover the probe surface with parafilm or other protective coating. Parafilm and similar materials will shield the low energy betas from C-14, P-33 and S-35 and may prevent the meter from detecting contamination.

Hold the probe window approximately 1 cm from the surface to be surveyed and move the probe over the surface at about 1 cm/second.

Check the most common sites for contamination, such as survey meter handle, soap/towel dispensers, drawer handles, refrigerator/freezer handles, chair edges, writing utensils, survey record books, floors, radio dials, telephone receiver/keypad, microwave oven touch pads/handles, doorknobs, light switches and non radioactive trash containers.

Record survey results in survey log. Generally, the surface is considered contaminated if the result is two times greater than the background count rate. If contamination is found, record the result and indicate the action taken.

5.2.2 Performing a Wide Survey

Prior to performing any survey, clean gloves should be worn. This prevents the possibility of personal contamination or cross-contamination.

Removable contamination is best identified by a wipe survey. Perform a wide survey by rubbing a filter paper (approximately 45mm in diameter) or cotton swab over the survey area with moderate pressure. The paper or swab may be wetted with ethanol or water to increase the collection efficiency. Usually an area of 100 cm^2 is surveyed. To monitor a larger area, take additional swipes.

If surveying for low-energy beta emitting isotopes such as H-3, C-14, P-33, S-35, etc, analyze the wipe using liquid scintillation counting.

If surveying for high-energy beta emitters (P32 etc), wipe samples may be counted using either liquid scintillation counting or a GM meter.

If monitoring for low-energy gamma emitters (I-125 etc), wipe samples should be counted with a thin crystal NaI scintillation meter.

The net sample count rate is determined by subtracting the background count rate from the gross count rate.

Sample activity is determined by dividing the net sample count rate by the instrument's efficiency for the isotope in question.

Survey results must be documented on a Survey Log. Results may be reported as gross count rate, net count rate, or in units of activity. Ensure the survey log accurately reflects how results are being reported.

All laboratories working with radioactive material shall be adequately ventilated and shall be provided with eye wash and emergency shower for decontamination purposes.

All operations likely to produce radioactive contamination of the air through the production of aerosols, smoke or vapours shall be done in a fume hood.

CHAPTER 6 EMERGENCY PROCEDURES

In any radiation emergency, personnel protection comes first, confinement of radioactivity next.

For accident/incident pertaining to non-ionising radiation, where an investigation confirms that there is exposure in excess of the limits permitted, the PI shall:

(a) Notify OSHE via http://www.nus.edu.sg/osh/ OSHE will then report to HSA if deemed necessary.
(b) Suspend the radiation worker from work in which he will be exposed to radiation.
(c) Arrange for medical examination of such radiation worker which may include eye examination and any other examination as may be required by the Authority and/or OSHE.
(d) Keep a record of the circumstances in respect of the radiation worker.

For accident/incident pertaining to ionizing radiation, the PI, the SHO or individual in charge of the area at the time shall:

(a) Evacuate all individuals from the affected area.
(b) Block off the affected area and post warning signs at all its entrances.
(c) Take immediate action to reduce the hazards caused by the radiation accident.
(d) Make arrangements to provide temporary shielding, monitor and decontaminate any affected individual and the area and take all other actions necessary to return the situation to normal.
(e) Ensure that any contamination in excess of the appropriate permitted contamination limit for skin and clothing of any individual is removed before the individual leaves the premises.
(f) Ensure that any personal clothing or other private property which is contaminated by radioactive materials is not taken from the premises or released to a public laundry until it can be shown that the contamination does not exceed the appropriate permitted contamination limit.
(g) Refer affected individuals for medical observation and treatment.

The PI shall inform OSHE of the occurrence of the accident by means of a preliminary oral report within 12 hours and via http://www.nus.edu.sg/osh/ , which is to be confirmed in writing within 24 hours and a final full written report within 5 working days.

OSHE will in turn report to HSA if deemed necessary.

CHAPTER 7 FACT SHEETS OF COMMONLY USED ISOTOPES

Tritium H-3	
Radiological half-life, $T_{1/2}$	12.3 years
Principle emission	18.6 keV beta (maximum)
Dose rate (1cm from a beta point source)	300 mrad/h per mCi
Annual limit on intake (ALI) by inhalation	1×10^9 Bq
Annual limit on intake (ALI) by ingestion	1×10^9 Bq
Biological monitoring method	Urine samples
Range in air	4.7mm
Range in water	6×10^{-3}mm
Shielding required	None
Monitoring method for contamination	Wipe survey
Limits for contamination of surfaces	1×10^3 Bq/cm^2

Special Considerations:

- Tritium compounds can be absorbed through the skin therefore gloves must always be worn. Consider wearing two pair of gloves.

- Place previously opened containers of tritiated water into a fume hood, not a refrigerator. Monitor storage areas where large quantities of H-3 are kept, as certain forms tend to “creep”.

- Due to its low beta energy, tritium cannot be monitored directly, and therefore regular wipe surveys of the work are recommended.

Carbon C-14	
Radiological half-life, $T_{1/2}$	5730 years
Principle emission	156eV beta (maximum)
Dose rate (1cm from a beta point source)	300 mrad/h per mCi
Annual limit on intake (ALI) by inhalation	4×10^7 Bq
Annual limit on intake (ALI) by ingestion	4×10^7 Bq
Biological monitoring method	Breath or urine samples
Range in air	21.8cm
Range in water	0.28mm
Shielding required	1cm plexiglass
Monitoring method for contamination	GM counter
Limits for contamination of surfaces	1×10^3 Bq/cm^2

Special Considerations:

- Use plexiglass shielding. Do not use lead shielding, which creates bremsstrahlung radiation.

- Do not generate carbon dioxide which could be inhaled.

Phosphorus P-32	
Radiological half-life, $T_{1/2}$	14.3 days
Principle emission	1.71 MeV beta (maximum)
Dose rate (1cm from a beta point source)	300 mrad/h per mCi
Annual limit on intake (ALI) by inhalation	5×10^6 Bq
Annual limit on intake (ALI) by ingestion	8×10^6 Bq
Biological monitoring method	Urine samples
Range in air	6.1m
Range in water	0.8cm
Shielding required	1cm plexiglass
Monitoring method for contamination	GM counter
Limits for contamination of surfaces	1×10^{-2} Bq/cm^2

Special Considerations:

- Use plexiglass shielding. Do not use lead shielding, which creates bremsstrahlung radiation.

- Wear eye protection.

Sulphur S-35	
Radiological half-life, $T_{1/2}$	87.4 days
Principle emission	167 keV beta (maximum)
Dose rate (1cm from a beta point source)	300 mrad/h per mCi
Annual limit on intake (ALI) by inhalation	3×10^7 Bq
Annual limit on intake (ALI) by ingestion	7×10^7 Bq
Biological monitoring method	Urine samples
Range in air	26cm
Range in water	0.32mm
Shielding required	1cm plexiglass
Monitoring method for contamination	GM counter
Limits for contamination of surfaces	1×10^3 Bq/cm^2

Special Considerations:

- Swipes counted by liquid scintillation.

- Some compounds, such as S-35 methionine, may vaporize upon opening of container. Therefore, open vials in fume hoods to prevent inhalation.

Chromium Cr-51	
Radiological half-life, $T_{1/2}$	27.7 days
Principle emission	0.32 MeV gamma (9.8%), 5keV X-ray (22%)
Dose rate (1cm from a beta point source)	18R/h
Annual limit on intake (ALI) by inhalation	2×10^8 Bq
Annual limit on intake (ALI) by ingestion	4×10^8 Bq
Biological monitoring method	Whole body count
Half-value layer	3mm lead
Monitoring method for contamination	NaI or other scintillation detector
Limits for contamination of surfaces	1×10^3 Bq/cm^2

Iodine I-125	
Radiological half-life, $T_{1/2}$	60 days
Principle emission	35 keV gamma (7%), 27-32keV X-ray (140%)
Dose rate (1cm from a beta point source)	1.4R/h
Annual limit on intake (ALI) by inhalation	2×10^6 Bq
Annual limit on intake (ALI) by ingestion	1×10^6 Bq
Biological monitoring method	Thyroid scan
Half-value layer	0.02mm lead
Monitoring method for contamination	NaI or other scintillation detector
Limits for contamination of surfaces	1×10^2 Bq/cm^2

Glossary of Radiation Terms

Activity (of a substance)
The number of disintegrations per unit time taking place in a radioactive material. The unit of activity is the Becquerel (Bq), one disintegration per second.

Background radiation
The ionizing radiation in the environment to which we are all exposed. It comes from many sources including outer space, the sun, the rocks and soil under our feet, the buildings we live in, the air we breathe, the food we eat, and our own bodies.

Contamination
Uncontained radioactive material which has been dispersed into unwanted locations.

Radioactive decay
The spontaneous radioactive disintegration of an atomic nucleus resulting in the release of energy in the form of particles (for example, alpha or beta), or gamma radiation, or a combination of these.

Absorbed dose
A measure of the amount of energy deposited in a material by ionizing radiation. The unit is the joule per kilogram, given the name Gray (Gy).

Equivalent dose
Equivalent dose is a measure of the biological effect of radiation on a tissue or organ and takes into account the type of radiation. The unit is the sievert (Sv), bout doses are usually measured in millisieverts (mSv) or microsieverts (µSv).

Dosimeter (or Dosemeter)
A device used to measure the radiation dose a person receives over a period of time.

Dose limits
The maximum radiation dose, excluding doses from background radiation and medical exposures, that a person may receive over a stated period of time. In Singapore, the dose limit for radiation workers is 20mSv/year and 1mSv/year for individual members of the public. The dose from any medical or dental exposure as a patient or from the exposure to natural background radiation shall not be taken into account.

Radioactive half-life
For a single radioactive decay process, the time required for the activity to decrease to half its value by that process. Half-lives vary, according to the isotopes, from less than a millionth of a second to more than a billion years.

Ionising radiation
Radiation capable of causing ionization of the matter through which it passes. Ionising radiation may damage living tissue.