RADIATION PROTECTION NOTE 7:
THE INTERNAL RADIATION HAZARD & THE USE OF RADIOACTIVE MATERIALS

INTRODUCTION

When radioactive material is enclosed within a container it may give rise to an external radiation hazard but when it is not contained it may constitute an internal radiation hazard. There are three ways in which radioactive materials may enter the body: inhalation, injection or skin absorption.

Inhalation

Inhalation is the commonest cause of intake and when contamination is present in the atmosphere it will be breathed into the lungs and a certain amount will pass into the bloodstream. Another fraction will be eliminated from the lungs and swallowed and the remainder exhaled. The various fractions passed into the bloodstream, swallowed or exhaled depend on many factors such as the chemical and physical form of the contamination and the physiology of the person involved.

The use of tritiated radiochemicals may give rise to an evolution of HTO gas from the experiment and ^{14}C can sometimes produce radioactive CO_2. All experiments involving "wet" solutions have the potential to produce aerosols therefore it is always recommended to carry out these operations in a fume cupboard.

Injection

Injection is usually the result of careless handling or disposal of hypodermic needles, pipette tips and glassware. Once dispensing is completed, sharps should be disposed into a suitable receptacle designed for the purpose of preventing a puncture threat.

Skin absorption

Skin absorption may occur if the skin is contaminated with tritiated water or radioiodine. Open wounds should always be covered before entering a radiation area.

Whichever route radioactivity enters the body, an intake is very serious since as

1) Irradiation of tissue occurs over the whole 24 hour period and not just in the laboratory.
2) There is no distance protection within the body because the body cells are irradiated by the radiation within them.
3) Certain organs concentrate radioactivity within thus increasing the local radiation dose received. An example of this is the thyroid gland that concentrates radioiodine.

There is a relationship between the radiation dose received and a given intake of radioactive material before it is eliminated from the body. Knowledge of the metabolism of the particular chemical involved and the route of transport through the body is necessary to calculate the accumulated effective dose received at any given time after the initial intake.

THE ANNUAL LIMIT ON INTAKE (ALI)

The Annual Limit on Intake is defined in ICRP 30 (Part 1) as "The activity of a radionuclide which taken alone would irradiate a person, represented by Reference Man, to the limit set by the ICRP for each year of occupational exposure." The current dose limit for a radiation worker is set at 20 mSv/yr (IRR 17). We can use the ALI value to estimate the dose commitment for any particular isotope. Table 1 lists some ALI's of isotopes in common use within the University.

The calculated value of ALI for a particular radioisotope will depend on

1) The route of entry – ingestion, inhalation etc.
2) The chemical form, its solubility and metabolism in the body.
3) The particle size, as in the lung this will be important in determining the residence time.
4) The types and energies of the emitted radiations and the physical half-life.

When an intake of a radioisotope occurs, an estimate of the committed dose is usually calculated from a measurement of the activity present in a biological sample, such as urine. An example of such an estimate is given below.

Example 1: Thirty days after a worker was involved in a radiation accident involving a spillage of tritiated water (HTO), a measurement of the activity of HTO in 1 ml of urine gave a concentration of 150 Bq/ml. An estimate of the initial intake of HTO and the dose commitment proceeds as follows.

HTO is known to uniformly distribute throughout the body water, ICRP site 'Reference Man' as having water content of 42 kg (ie, 42 litres). Therefore the total activity of HTO present in the worker's body at the time of the measurement is 42000 x 150 = 6.3 MBq.

The biological half-life of HTO in the body is approximately 10 days (ICRP 23) therefore, when measured, the activity was only one eighth of that initially present. The initial intake is therefore 8 x 6.3 = 50.4 MBq. The ALI for tritium (Table 1) is given as 1 GBq, corresponding to a dose commitment of 20 mSv. Therefore the dose commitment of the worker is estimated to be 50.4 x 20 / 1000 = 1 mSv from the time of the accident.

An intake of a radioisotope emitting gamma or X radiation can often be estimated using external monitoring techniques such as whole body counting or thyroid monitoring with a type 5.42 scintillation counter probe.

ANNUAL LIMIT ON INTAKE TAKEN FROM ICRP 61

NUCLIDE	ALI (Bq)
^{3}H	1×10^{9}
^{14}C	4×10^{7}
^{18}F	4×10^{8}
^{22}Na	7×10^{6}
^{24}Na	5×10^{7}
^{32}P	5×10^{6}
^{33}P	3×10^{7}
^{35}S	3×10^{7}
^{36}Cl	3×10^{6}
^{45}Ca	1×10^{7}
^{51}Cr	2×10^{8}
^{55}Fe	3×10^{7}
^{59}Fe	5×10^{6}
^{60}Co	4×10^{5}
^{63}Ni	1×10^{7}
^{65}Zn	4×10^{6}
^{75}Se	9×10^{6}
^{90}Sr	6×10^{4}
^{99m}Tc	1×10^{9}
^{125}I	1×10^{6}
^{131}I	8×10^{5}
^{134}Cs	1×10^{6}
^{137}Cs	1×10^{6}
^{210}Pb	1×10^{4}
^{226}Ra	9×10^{3}
^{232}Th	9×10^{1}
^{238}U	6×10^{2}
^{239}Pu	3×10^{2}
^{241}Am	3×10^{2}

PRECAUTIONS IN THE USE OF UNSEALED RADIOACTIVE MATERIAL

Setting up the Experiment

Always use the least radiotoxic isotope and bear in mind that, in the event of a spillage resulting in the contamination of the laboratory, the problem will be most serious where the half-life is very long.

The activity of the isotope used should be the minimum consistent with obtaining good statistical data.

Know the physical and chemical properties of the material in use and guard against the unwanted production of aerosols and gases. Know the types and energies of all the radiations emitted and the detection efficiencies of the monitors in use.

Carry out a 'dummy run' of the experiment before proceeding to the use of radioactive material.

The Working Area

Depending on the actual radioisotope in use, experiments with unsealed material will be carried out in either a 'Controlled' or 'Supervised' radiation area.

Controlled areas have the highest standard of surface finishes and will usually have a superior fume cupboard. Dispensing from stock solutions of radioisotopes should always be carried out in this fume cupboard to avoid the inadvertent inhalation of gases and aerosols. The main disposal drain is usually located in this area.

Supervised areas also have high surface finishes to facilitate decontamination in the event of a spill but there may not be access to a modern fume cupboard. These areas are not exclusively devoted to the use of radioactive materials and access is unrestricted. Limits are placed on the activity of radioisotopes that may be handled or stored in these areas.

In setting up an experiment in a supervised area, the radioisotope work should be segregated from other activities in the laboratory and, where possible, this area should be used for all such experiments. The worktop should be free from clutter and unnecessary equipment and should be covered with 'benchkote' matt side uppermost (ie, shiny side down). Radiation warning tape should be used sparingly to demarcate the area. The floor adjacent to the worktop should be free from tripping hazards and stored apparatus that might become contaminated in the event of a spill.

Working Procedures

All manipulations should be carried out over a spill tray lined with tissues. This elementary precaution, besides protecting against the spread of contamination, greatly reduces the time spent eliminating the small spots of contamination on the working surface that may occur even with the best handling techniques. Any small contamination on the tissue in the tray is easily disposed of and, as it is only exposed to air for a short time, its contribution to air contamination in the laboratory is kept to a minimum. Active and potentially contaminated apparatus should be kept on the tray with clean apparatus remaining on the bench. Radiation warning tape should be used to indicate actual or potential contamination but should not be used indiscriminately.

A box of disposable tissues should be available to wipe and wrap contaminated pipette tips etc and a container should be provided on the tray to collect the soiled tissues. In addition, the tissues can be used to handle potentially contaminated apparatus thus preventing contamination of gloves and they can also be used when handling uncontaminated objects such as taps, monitor controls etc.

Care must be taken to avoid droplets and aerosols: mixers and homogenisers are particularly suspect in this matter and should always be used in a fume cupboard. When an elutant is collected from a column, the drops from the tip should not be allowed to splash unnecessarily into a container. Similarly, care should be taken not to 'flick' the points of hypodermic needles. This is most important where high specific activity solutions are used as even the smallest droplet may carry an activity of several hundred kilobecquerels. Disposable apparatus should be used where high specific activities are required. When decontaminating apparatus, first thoroughly rinse it out

before it is placed in ‘Decon’ to soak for a length of time. Care should be taken to avoid spilling these solutions as this is often a frequent cause of low level contamination.

Radioactive Waste

Radioactive waste should always be disposed at the earliest convenience.

Aqueous waste should be diluted to at least a litre volume before carefully pouring into a smoothly flowing stream of water at the designated disposal sink. Do not cause splashing and let the water run for sufficient time to clear the radioactivity from the surrounding sink and pipework. In all cases the activity and isotope should be logged in the book, sheet or computer provided.

The cost of disposing solid radioactive waste to landfill has trebled since January 2000, therefore it is most important that this waste is monitored to determine whether or not it is actually radioactive. It is estimated that over 50% of the contents of a bin of radioactive waste is non-radioactive.

Solid radioactive waste in the form of soiled tissues etc should be placed in the bins provided. Items containing significant activity should be separately packaged and labelled. Unused radioisotopes should not be discarded as solid waste but should be disposed of to liquid waste whenever possible.

Hypodermic needles and pipette tips must be made safe before disposal or placed in special 'sharps' bins. Waste bins must be emptied regularly and the contents securely packaged before being sent to the Radiation Protection Service for ultimate disposal. The package should bear the correct label with the details of date, department, laboratory, radioisotopes and activity (in Bq) completed. In many cases the activity will have to be an estimate based on throughput of radioisotopes in the laboratory in question. The Scottish Environmental Protection Agency (SEPA) require a complete history of all radioisotope usage from purchase to disposal so it is important that all waste is accompanied by correctly completed labels.

Personal Hygiene, Protective Clothing etc

To avoid an internal intake of radioactive material, pipetting by mouth, eating, drinking and the application of cosmetics are forbidden in areas where unsealed radioactive materials are in use. Disposable paper handkerchiefs or tissues should be used in preference to personal ones and should be disposed to radioactive waste after use.

A buttoned up laboratory coat should be worn with a radiation dosimeter at chest height. Disposable gloves must be worn for all manipulations of radioisotopes. If not used properly, gloves can spread contamination. The outside surface of gloves should always be regarded as contaminated and should be checked frequently.

Clean disposable tissues should be used for the operation of switches or other objects that might later be touched with bare hands.

Thin latex gloves are not completely impervious to some radioiodine compounds and two pairs should always be worn. Domestic household gloves may be preferred but these tend to be cumbersome. Exercise care when removing and disposing of gloves to avoid skin contamination. When dispensing or manipulating high activity stock solutions, a disposable plastic apron should be worn and discarded to radioactive waste when finished.

CONTAMINATION MONITORING

With the exception of the use of Tritium, a contamination monitor should be turned on and frequently used throughout the whole of any manipulation of radioactive material and the worker should be aware of its response to the radiations present. For beta radiation a 1” end window Geiger-Muller ‘minimonitor’ is the most generally useful instrument; however, it is not suitable for monitoring tritium or electron capture nuclides such as ^{51}Cr or ^{125}I.

The monitor should first be set to the "battery check" position and left for about ten seconds. If the needle is not on or above the indicated ‘good’ area then the batteries should be replaced. The minimonitor should not be left in the "battery check" position when not in use as this will drain the batteries. Do not keep switching the monitor on and off: it will give a better performance if left on

until the experiment is finished. As the experiment proceeds, use the monitor to check items of equipment for contamination and check the fingers frequently.

At the end of the experiment, tidy away the apparatus – checking for contamination as you go. Monitor the spill tray, working area, front of the bench and floor. In the case of ^{14}C and ^{35}S, hold the probe close to the surface being monitored and do not move it too quickly. Listen for variations in the number of 'clicks' on the monitor loudspeaker, scan methodically and home in on any spots of contamination found.

Contamination spots can be suitably marked as the check proceeds and then decontaminated at the end of the search. When decontaminating, work in from the least contaminated part to the most active and avoid spreading contamination by excessive use of 'Decon'. Tissues or cloths soaked in Decon and placed over an effected area can be very effective in removing contamination.

All contamination should be kept as low as reasonably practicable. The University has adopted the approach of setting an 'Action Level' for surface contamination levels. Any contamination above this level is deemed to be unacceptable and will require decontamination procedures to be implemented. In Glasgow University, this level has been set at 3 $Bqcm^{-2}$. Each minimonitor in current use will have a label attached to the side giving the monitor's response to the 3 $Bqcm^{-2}$ level. Please note that the figures quoted are the response above background (ie, add to your normal background count)

Skin Contamination

For small areas of skin contamination, contamination by beta emitters is more serious than the risk from gamma emitters on account of the higher dose rate to the basal layers of the skin produced by beta radiation. This dose rate, to a first approximation, does not depend on the energy of the beta particle and we find that a contamination of 1 $kBqcm^{-2}$ produces a dose rate of 0.5 mSv/hr at the basal layer of the skin. For very low energy betas, this dose rate is higher.

Contamination Monitoring for Electron Capture Nuclides

Electron Capture nuclides such as ^{51}Cr and ^{125}I do not emit beta particles and the X-ray and gamma ray photons that are emitted have a detection efficiency of < 1% in a 1" Geiger-Muller minimonitor. It is necessary to use a detector specifically designed for this type of radiation. Such a detector is the Type 5.42 Minimonitor scintillation probe. The probe has a 22x1 mm NaI crystal with a detection efficiency of ~ 90% for the 27 keV photons emitted by ^{125}I (The response of the probe to ^{51}Cr and ^{125}I is given in table 2). Even so, the response of the probe to surface contamination levels of around 3 $Bqcm^{-2}$ is barely adequate and if the contamination of a surface is in doubt, it is always possible to take a swab of the area and count it with more sensitive equipment.

Radionuclide		Response (above background)
3 $Bqcm^{-2}$	^{51}Cr	0.1 cps
3 $Bqcm^{-2}$	^{125}I	1.7 cps

Table 2: Response of type 5.42 Probe

The probe has a lead-collimating shield surrounding the NaI crystal giving the probe a directional response which can be used to advantage when looking for contamination. The probe is also very sensitive to external radiation fields, for example, 1 μSv/hr of the 28 keV X-radiation emitted by ^{125}I will produce a count rate of approximately 1000 cps. This makes it difficult to detect contamination if there are nearby sources of ^{125}I.

Thyroid Monitoring for ^{125}I Intakes

The type 5.42 probe can be used to estimate an intake of ^{125}I since it is known to accumulate in the thyroid gland. Maximising the count rate at the Adam's Apple, we find that 1 kBq of ^{125}I in the thyroid will give a count rate of ~ 10 cps above background corresponding to a thyroid dose commitment of 1.35 mSv = effective dose of 70 μSv.

The Radiation Protection Service keeps a type 5.42 probe for the purposes of thyroid monitoring and it is available on loan from the RPS, Kelvin Building ext. 4471.

Monitoring an Intake of Tritiated Water

Following an intake of tritiated water, or a compound labelled with tritium which is metabolised to water, the tritium is uniformly distributed throughout the water in the human body.
To make an estimate of the dose commitment we measure the concentration of tritium in a morning sample of urine.

Example A measurement of 1 ml of urine in a liquid scintillation counter gave a count rate of 4800 disintegrations per minute (dpm) in the tritium channel. If the counting efficiency for this machine was 25%, estimate the dose commitment, given that the intake occurred 30 days before the measurement was made.

Answer 4800 dpm = 80 dps
80 dps at 25% efficiency = 320 Bq/ml
321 Bq/ml = 13.44 MBq in total body water

The ALI for HTO is $1x10^9$ Bq => dose commitment 20 mSv
$\therefore$ 13.44 MBq => 13.44x20/1000 = 0.269 mSv
$\therefore$ Dose commitment at time of measurement is 0.269 mSv

The biological half-life of HTO is 10 days $\therefore$ three half-lives have passed since the initial intake. The resulting dose commitment from initial intake is thus 8x0.269 = 2.15 mSv

Wipe Testing of Surfaces

There is no convenient way of monitoring tritium contamination in situ and we must resort to the wipe test method. A lightly damped piece of filter paper or cotton wool is wiped over on area of 10x10 cm and then placed in a liquid scintillation counter vial with a measured amount of ecoscint and counted in a LSC. It is usual to assume that only 10% of the unfixed contamination is removed on the swab.

Example A swab taken from 100 cm^2 of work surface produces a count rate of 240 dpm in the tritium channel of a LSC. Estimate the level of contamination present given the counter has a counting efficiency of 25% for tritium.

Answer 240 dpm = 4 dps
At 25% efficiency = 16 Bq on swab
Assume 10% pick-up = 160 Bq over area 100 cm^2
$\therefore$ contamination level = 1.6 $Bqcm^{-2}$.

The wipe test can be used for any contamination provided the counting efficiency is known.

HIGH SPECIFIC ACTIVITY MATERIALS

Many labelling materials have high specific activities, eg ^{125}I can be obtained with a specific activity of 20 GBq/ml. A droplet of 1 ml will contain an activity of 20 MBq and a single aerosol droplet may contain 20 kBq. Generation of aerosols in such circumstances is disastrous and all manipulations of high specific activity materials must be carried out in a fume cupboard. It is also worth noting that vials of radioiodine for labelling invariably contain 1% of their activity in the form of free iodine vapour which is likely to be released when the vial is opened.

CONCLUSION

Generally speaking, the internal hazard is the principal hazard encountered in the use of unsealed radioactive materials in Universities. To protect oneself and one's colleagues, clean, uncluttered and methodical procedures should be employed with attention to the containment of radioactive material, careful disposal of waste and the prevention of contamination.