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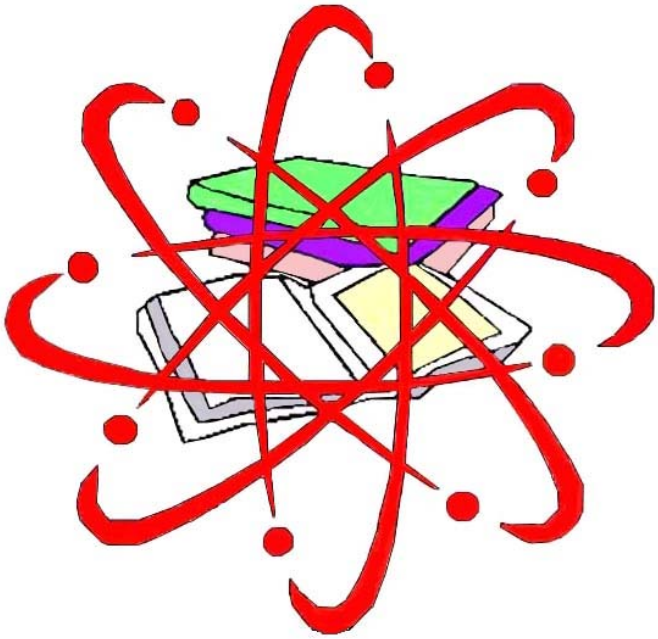
Distance Assisted Training Programme for Nuclear Medicine Professionals

Edited by: Heather E. Patterson, Brian F. Hutton



Radiation Safety – Part 2

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John Cormack

Module 2 Unit 2b

(version 4.1)

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Radiation Safety - Part 2

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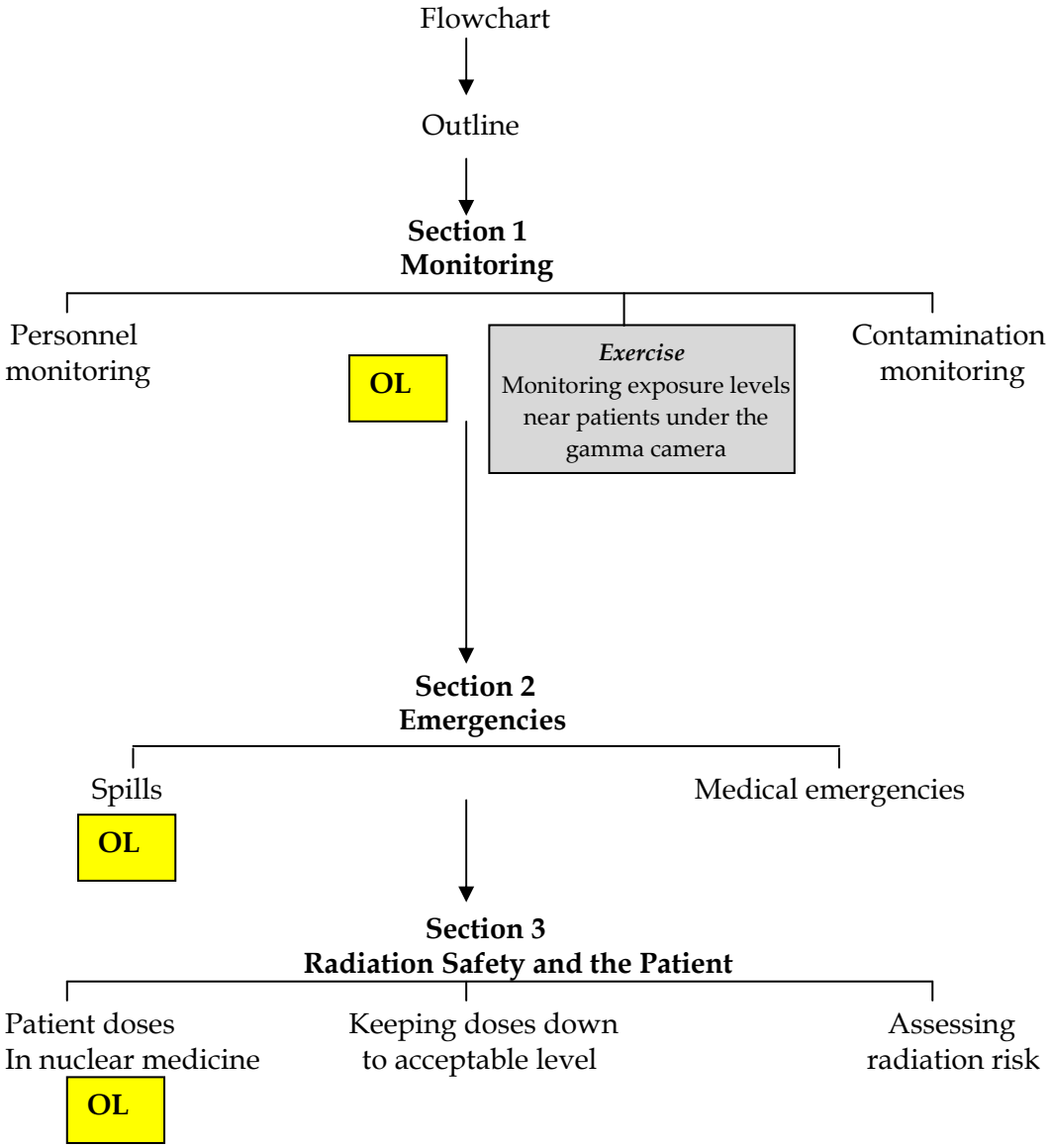
Part 2



OL On-line exercise

Radiation Safety Part 2

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Outline:

In Basic Radiation Safety Part 1, we looked at the causes of radiation exposure to staff in a nuclear medicine department, and how to carry out routine tasks with a minimum of exposure. In this Unit 2b, there are three sections

- how to check that staff exposure is as low as it can reasonably be,
- how to cope with emergencies that can happen occasionally in any department,
- radiation exposure from the patient's point of view.

1. Monitoring

It is important to have a formal system for trying to improve and maintain a high standard of work performance, in nuclear medicine or anything else. This is sometimes called "quality assurance" and "quality improvement", and depends on *monitoring* what is going on. For example, there have to be continuous checks on the performance of gamma cameras and the quality of images given to the physician for interpretation. It is just as important to monitor workplace safety and patient safety when using hazardous substances like radioactivity. You may do your own monitoring, or if it is done by someone else there must be "feedback" so you are given the results and can see where there might be room for improvement.

2. Emergencies

From time to time something unusual will happen in any nuclear medicine department which will require a quick response. It may be a medical emergency involving the patient. It may be some loss of control over radioactive material - usually a spill. Luckily, most events like these in nuclear medicine are minor. If you think ahead about what could go wrong, make sure you have the equipment you need to deal with the situation, and everyone knows what to do, then minor situations will not escalate into major problems.

3. Radiation Doses to Patients

Patients accept that what the nuclear medicine doctor is doing is for their benefit, but they may still be worried about being radioactive. Nuclear medicine staff should know how much radiation they are exposing their patients to. They should be able to reassure patients about the risks, and tell patients about any precautions they should follow to avoid exposure to their families.

This unit does not include much practical work. Its purpose is to put the radiation aspect of Nuclear Medicine into perspective, so that you are comfortable with your work and caring for your patient.

Time Check: ⌛

Allow about **7 hours** to study this unit, complete all exercises and record results in your Workbook.

Section 1

Monitoring

Introduction:

It important to be able to monitor
people - for external exposure and contamination
the workplace - for dose rates and contamination

You have already been asked to do some radiation monitoring in Basic Radiation Safety Part 1as follows:

- to survey dose rates in your workplace, using a portable survey monitor,
- to check for contamination on packages, using wipe tests,
- to list the external radiation doses recorded by staff on their personal monitors.

Not many departments have a variety of radiation monitors to suit every purpose. You may need to take an innovative approach to monitoring.

For example :
If you need to check your hands for contamination, everyone has access to a gamma camera which is the most sensitive detector of all for the radiations you are using for imaging purposes. Make sure the camera setting is correct for the radionuclide you have been handling.

Objectives:

On completion of this unit you will be able:

- To judge the significance of personal dosimeter readings
- To monitor exposure levels near patients
- To monitor yourself and the workplace for contamination

1. Monitoring of Personnel

Do you wear a personal radiation monitor? If you do, you may need help from your supervisor to answer the questions below.

Time Check: ⌛

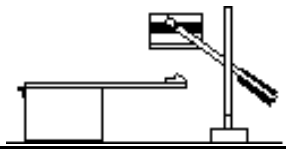
Allow **1 hour** to read the following and answer the questions.

Prerequisites:

📖 Read about radiation monitoring in a nuclear medicine textbook.
For example: Nuclear Medicine and PET/CT: Technology and Techniques
P.E.Christian, K.M.Waterstram-Rich, Elsevier – Health Sciences Div. 7th edition – 2011

☞**Go To** your workbook **section BRS** and answer the **questions 15-23. Not just one word answers - try and give reasons, and discuss arguments for and against.**

Prepare for an exercise near to your gamma camera



2. To Monitor Exposure Levels near patients under the gamma camera

Introduction:

Most of a technologist's exposure comes from radiation emitted by injected patients. By measuring the exposure rate near patients and knowing how much time is spent handling the patient, you will be able to identify how much the different imaging procedures contribute to your overall exposure.

Objective:

On completion of this exercise you will know how

- To monitor exposure levels near patients under the gamma camera.

Time Check:

Allow **1 hour** to complete the following exercise.

Materials:

To proceed with this exercise you will need:-

- A portable survey monitor, preferably one with a dose rate read-out, e.g. microsieverts/h, micrograys/h, millirads/h.
  (NB. milliRoentgens/h is approximately the same as millirads/h or millirems/h)

Typical Doserate Meter reading scale in µSv/hr
Figure 7a

Typical Contamination Monitor reading scale in counts/sec.
Figure 7b.

Monitors may have internal and/or one or more external detectors (probes).

Good Idea!

It is a good idea to protect the detector with a thin sheet of plastic cling wrap ("Cling film / plastic wrap"); this will make decontamination easier if the detector becomes contaminated while monitoring, Except for the case of very low energy beta emitters such as C-14, this will not affect the detection capability of the monitor.

Remember

1 mrad/h = 10 μGy/h 1 mrem/h = 10 μSv/h
1 mR/h = 8.7 μGy/h

If your monitor does not have a dose rate read-out, but has scale readings in count rates (eg. counts per second or counts per minute), you can determine an approximate calibration factor. You will need:-

- a source of about 1 GBq ^{99m}Tc, to obtain an approximate 'calibration factor' for your monitor.
  For example: A bone scan dose in a syringe which you have just measured in the dose calibrator would be suitable.

THINK!

The following exercise will involve you using your radiation monitor and taking readings at different times over the next few days or weeks.
Ensure all the materials needed are ready and available - this will save time!

Procedure:

i) Calibrate your Survey Monitor if the Scale is not in Dose Rate Units.

Find out the count rate reading on your monitor at 1 metre from a little ("point") source of about 1GBq of ^{99m}Tc. Do this in a room with the lowest background possible. Check the battery and measure the background first, then place the unshielded source on a support about 1.5 metres above the floor and 1.5 metres away from the walls or other scattering objects. Measure the source on your monitor at a distance of 1 metre.

B = background reading in counts/sec or counts/min_____
S = source reading in counts/sec or counts/min_____
A = source activity in megabecquerels or millicuries_____

Now let us work out a calibration factor, k, for ^{99m}Tc.

The dose rate at 1 metre from a point source of 1MBq of technetium-99m is about 0.016 μGy/h. neglecting a little attenuation in the source and its container walls. If you are working in the old system of units, this would be equivalent to 0.056 mrad/h at 1 metre from a 1 mCi source.
Assume the dose rate from a source A is D μGy/h, and D is proportional to the monitor reading (S-B) therefore D = k(S-B)
Dose rate at 1m from 1 MBq of ^{99m}Tc = 0.016 μGy/h
Therefore dose rate at 1 m from A MBq = (0.016 x A) μGy/h

Hence:

$$0.016\ A\ \mu Gy/h = k(S-B)$$

and $$k = 0.016\ A/(S-B)$$

If you measured your ^{99m}Tc source activity A in MBq:
k = 0.016 x A/(S - B)
And you can convert the count rate readings on your meter to μGy/h in future by multiplying them by this value of k.

If you measured your source activity A in mCi:
k = 0.056 x A/(S - B)
And you can convert the count rate readings on your meter to mrad/h in future by multiplying them by this value of k.

The value of k will be different for other radionuclides, because monitors do not have exactly the same response to all photon energies. In fact many survey meters have been calibrated with the radionuclide caesium-137. Unless they are "energy compensated" they will not be accurate for ^{99m}Tc.

Attach a note to your monitor

> "**For ^{99m}Tc energies, readings can be converted to μGy/h by multiplying by .....**"
>
> **OR**
>
> "**For ^{99m}Tc energies, readings can be converted to mrad/h by multiplying by .....**".

ii) Now collect dose rate data near patients who are under the gamma camera.

Over several weeks, measure the dose rates (or count rates) near patients who are having ^{99m}Tc studies. Try to get readings from about five patients in each of the four nuclear medicine studies shown in the table below, or substitute the four studies most commonly performed in your department if you like.

Place your monitor at a measured distance of 30 cm to one side of a patient lying under the gamma camera detector, at about the level of the patient's costal margin. Wait for the meter reading to stabilize, and record the result. Repeat at a distance of 1 metre.

Fill in the following table

^{99m}Tc Study	Usual administered activity * MBq or mCi	Distance	Five dose rate or count rate readings	Average dose rate**
Bone		**30 cm**		
		100 cm		
GHPS		**30 cm**		
		100 cm		
Thyroid		**30 cm**		
		100 cm		
Renal		**30 cm**		
		100 cm		

* The activity remaining in the patient when you measure the dose rate will be less, due to radioactive decay and biological excretion.

** Converted from count rate to dose rate if necessary because of your survey monitor scale.

 **Go to** powerpoint demonstration on use of contamination monitor **LINK**

☞**Go To** your Workbook **section BRS** and answer the **questions 24 - 26** which relate to the results of the exercise just completed

3. To check yourself and the workplace for contamination.

Time Check:

Allow **30 minutes** to read the remainder of this section

Introduction:

A sensitive monitor is the best safeguard to warn against contamination. Generally, Geiger counters are the cheapest, and are most sensitive for beta rays and internal conversion electrons (remember them?).

Contamination monitors should have a large sensitive detector area called a "window". A thin window thickness (less than 4 mg/cm^2) allows beta rays to penetrate to the chamber inside. Sometimes the window has a sliding aluminium cover which can be used to separate beta rays (which can not get through the window) from X- and gamma rays. Wall-mounted monitors are convenient for checking the hands near the hot lab, but a portable monitor is also needed.

Figure 7c. Monitor for checking contamination of hands.
Courtesy of : Global Medical Solutions, Australia, Pty, Ltd.

Wipe Tests:

Not all nuclear medicine workplaces have contamination monitors. There will be areas where the background dose rate is too high for the radiation monitor to detect surface contamination at the very low levels needed. In these situations, we use wipe tests, just as you did in Unit 2a to look for contamination on packages of radioactive material when they arrived. A wipe test is best done with a small absorbent piece of cloth like a swab. It should be moistened with water or alcohol, and held in forceps. An area of about 100 cm^2 should be 'swiped', rubbing firmly with the swab. If the contamination is removable, activity can be detected on the swab with a radiation monitor, well counter, or the gamma camera. (The dose calibrator is not sensitive enough to detect the small levels of activity which you need to know about.) Be careful not to contaminate the detector - put the swab in a clean counting tube or plastic bag before counting.

It is actually very difficult to measure surface contamination accurately in units of Bq/cm^2 or μCi/cm^2, even with a calibrated contamination monitor. The amount of contamination removed by the wipe will vary with the type of surface and how long it has been contaminated. However, in nuclear medicine practice it is usually enough to know whether there is any contamination present or not, in order to deal with it straight away and plan how to avoid it in future.

Work surfaces

With short-lived radionuclides, it is best to monitor at the end of each working day. Any contamination must be cleaned up immediately. Any stubborn contamination, which resists further cleaning, should be covered with plastic sheet and marked with the date, radionuclide and contamination level (cps or μSv/h). Shielding with perspex (for betas) or lead (for gammas) may be needed while the radioactive contamination is allowed to decay.

Do not forget that equipment including the gamma camera itself, the dose calibrator, and the well counter, might be contaminated. With the gamma camera, check the background reading each day with the collimator on. With the dose calibrator, check the background reading. If it is high then remove the chamber lining and recheck the background reading. This should tell you whether the high reading is due to contamination of the lining, or to other sources standing near the chamber.

Whenever you use a well counter, always count a set of samples in the following order:

i) background,
ii) counting standard or reference source,
iii) samples,
iv) counting standard or reference source,
v) background.

Using this sequence, you can see from the background count whether the counter was contaminated to start with, or became contaminated during your measurements. You can also tell from the standard count whether the instrument's sensitivity drifted, either during use or since the last time it was used. All background and reference counts should be recorded in a log book, to help identify long term drifts and changes.

Have you ever seen hot spots on a nuclear medicine image which were caused by contamination? It can be on the patient's skin or hair, on handkerchiefs in a pocket, on the bed linen, on the collimator, or even on the crystal itself.
If you do not have a well counter or radiation monitor, the gamma camera will be useful for checking contamination.

- You can check your thyroid 24 hours after handling 'wet' ^{131}I.
- You can check your head after doing lung ventilation studies.
- Most importantly, you can check your gloved hands after preparing radiopharmaceuticals, injecting doses, cleaning up after incontinent patients. and anything else you think would be useful.

- Always be careful not to contaminate the monitor, gamma camera or the counter.

In practice, if you have wipe tests or contamination monitor readings more than twice the background level when there are no patients or other sources nearby, you have a contamination problem which needs to be carefully checked out.

Key Points:

- Personal monitor (film, TLD, OSD or electronic) results show you how good your radiation protection measures are:
- Nuclear medicine technologists should aim to keep their whole body dose at or below 3mSv to 5mSv (300 - 500 mrem) per year, even in busy departments.
- Wipe tests, radiation surveys and regular hand monitoring can alert you to the presence of radioactive material which has escaped its container.

Section 2

Emergencies

Introduction:

The most likely event, which can create an emergency, is a major spill in the department, or if the patient is suddenly taken very ill.

Objectives:

On completion of this section you will know how:-

- To respond to a spill and to decontaminate staff and the workplace.
- To respond to a medical emergency

Now is the time to read through a good textbook and see how much you understand. Are there any good books or teaching notes on radiation protection in nuclear medicine in your workplace?

Time Check:

Allow **2 hour** to read and study this section 2.

Prerequisites:

Read about Spills and Accidents in your nuclear medicine textbook.

For example: Nuclear Medicine and PET/CT: Technology and Techniques
P.E.Christian, K.M.Waterstram-Rich, Elsevier – Health Sciences Div. 7th edition - 2011

1 SPILLS

Sooner or later, some radioactive liquid is going to get spilled in a nuclear medicine workplace. It is important to deal with the spill immediately to stop it spreading further, minimise absorption on contaminated surfaces, and minimise evaporation. .

With ^{99m}Tc spills, the amount of activity is unlikely to be a hazard to staff but it is important to stop contamination spreading before it can cause problems with cameras and counting equipment.

With ^{131}I spills where liquid iodine is handled in large quantities, for example during radioiodinations or treatment of thyroid disease, any spill **is** potentially hazardous. There is a risk from the release of ^{131}I to the air as the spill evaporates.

Note: If you use liquid 'wet' ^{131}I, keep an alkaline solution of sodium thiosulphate or sodium bisulphite ready to pour over any spill and minimise the release of iodine vapours.

Remember

There is also a risk of absorbing iodine through contaminated skin, as well as inhaling iodine vapours. It is a good idea to have a supply of stable iodine handy. The hospital pharmacy might be able to provide you with a bottle of Lugol's iodine solution or potassium iodide tablets to keep for an emergency. A dose of 100 - 200 mg of stable iodine taken orally can block the uptake of radioiodine in the thyroid. It should be taken only on the advice of the nuclear medicine physician. If there is no Lugols iodine or potassium iodide available, the thyroid can be blocked by swabbing your skin liberally with 20mLs of an iodine-based skin disinfectant. [Stable iodine is also useful to protect the thyroid of patients given radiopharmaceuticals like ^{131}I - MIBG]

A decontamination kit should always be kept fully stocked and handy to the work area. The kit can be kept on a small trolley or a plastic bucket or box, which are easy to move around the department in a hurry.

The kit should contain:

- A radiation survey meter, and spare batteries
- A couple of sets of protective clothing
  - Gowns, disposable overshoes, disposable gloves
- Personnel decontamination equipment
  - Soap, a soft nail brush, gauze swabs or other soft wipes
  - Iodide tablets or Lugol's iodine if ^{131}I is used in large amounts
- Surface decontamination equipment
  - bucket or bowl
  - absorbent paper towels and disposable cloths
  - forceps or tongs, scissors
  - detergent solution, preferably in a small spray bottle ready for use.
  - alcohol swabs for wipe testing
  - plastic bags for contaminated cleaning material, linen,
  - a rigid plastic bottle or proper sharps container for broken glass, needles etc.
  - a spare lead pot for 'hot' items
  - an alkaline solution of sodium thiosulphate or sodium bisulphite
- Warning signs to prevent entry, marker pens to outline contaminated areas, tape for sealing waste bags etc.
- An information card outlining spill control and decontamination procedures, contact phone numbers, list of kit contents.

Remember

When a spill occurs, the first step is to bring the situation under control while protecting yourself from contamination:

- let other staff know and warn them where the contaminated area is
- reassure any patient who may be involved in the spill
- call for assistance and the decontamination kit
- put on gown and gloves if you are not contaminated
- contain spread of spilt material: cover with absorbent paper

The second step is to attend to any contamination on yourself or other persons:

NOTE: If there has been exposure to radioiodine from inhalation or absorption through skin, find out if stable iodine should be given to block thyroid uptake of radioiodine. Ask the nuclear medicine physician/doctor about this straight away. After 6 hours of exposure, there is little benefit to be gained.

Apart from the therapy radionuclides like ^{131}I, ^{89}Sr or ^{90}Y, the radionuclides and quantities used for diagnostic scan procedures do not require drastic decontamination methods.

The following methods should prove adequate.

Eyes	irrigate gently for 5 minutes preferably with sterile saline to avoid irritation of conjunctiva
Skin	wash gently with soap and cold water, do not scrub skin as this will remove natural oils and may abrade skin making it permeable to surface contamination. use water only on mucous membranes of nose and mouth; avoid spreading surface contamination, especially to nose, mouth and eyes. if contamination persists, moisten skin lightly with emollient skin cream and cover with plastic film or disposable gloves for an hour, remove covering and wash skin again.
Hair	wash thoroughly with mild shampoo, while wearing disposable gloves
Nails	scrub with soft nail brush, cold warm water and soap. Trim long fingernails.
Incorporated activity	following absorption, ingestion or inhalation of radionuclides, it may be possible to accelerate the excretion eg. by use of blocking agents, chelating agents, or hydration but this is very rare and needs specialist advice. See note on radioiodines above.

The third step is to decontaminate the workplace:

Work benches should not be contaminated if protected by spill trays and disposable absorbent paper. Floors, fume hood and centrifuge interiors and sinks are potential problem areas for decontamination.

When cleaning surface contamination:

- wear overshoes, gown and disposable gloves.
- double gloving with frequent changing of the outer gloves is recommended for large clean-up jobs, or when cleaning radioiodine spills.
- prevent people from walking through the contaminated area, by marking off the 'dirty' area from the 'clean' area with **CAUTION RADIATION** tape or similar
- survey and mark the contaminated areas, check for presence of ‘sharps’ such as needles and broken glass.
- moisten absorbent paper or cloth with detergent, and wipe up the spill carefully **always working inwards from the edge of the contaminated area.**
- discard used cleaning materials immediately into a plastic waste bag.
- monitor area and repeat as necessary.
- seal and label all bags of waste.

Finally:

Monitor the area of the spill again to make sure nothing has been overlooked. If the surface contamination can't be removed, it will be necessary to cover it with heavy duty plastic sheet while the activity decays, and possibly restrict people's access to the area.

- **Have a 'de-briefing'.**
  Discuss the incident with your supervisor and other staff, to see if there are any suggestions how to avoid similar incidents in future. You may be asked to write a simple report as a record.

 **Go to** video on Monitoring for Contamination **LINK**

Dealing with the contamination of a patient during a nuclear medicine study.

You have not been given a practical exercise for this section. Instead, when an assessor comes to visit your department you will be asked to show what you would do in the following simulated situation. You should apply the methods of spill management described in the previous pages.

Objective:

During the assessors visit you will be able:-

- To demonstrate how to deal with the situation where a patient in the middle of a renal scan has been incontinent of urine, wetting the scanning bed, linen, the camera detector head under the bed, and the floor.

Materials:

Have you got a decontamination kit ready?

2. MEDICAL EMERGENCIES.

It is very rare, but sometimes emergencies happen to nuclear medicine patients particularly in hospitals where they may be in poor health. They may have a cardiac arrest, or need to be transferred to an intensive care unit or to the operation theatre for emergency surgery. Staff should take radiation precautions with patients who have had radionuclide therapy, especially large doses of ^{131}I for thyroid cancer but this should NEVER delay prompt treatment of the patient. No special precautions are needed when dealing with diagnostic scan patients.

Patients being treated with large amounts of radioactivity - sealed sources like iridium-192 as well as ^{131}I and other radionuclides – should always be clearly identified, as soon as treatment commences. Usually a **CAUTION RADIATION notice** is placed on the door of the patient's room, or on the foot of the bed. It should certainly be put in the patient's medical notes. The patient should wear a special wrist band identifying them as a radiation hazard.

The amount of radiation coming from radionuclide therapy patients is <u>not</u> a barrier to standard emergency procedures. For example, working for as long as 30 minutes at 0.5 m from a high activity iodine-131 patient results in less exposure to a staff member than having a typical diagnostic x-ray or nuclear medicine test. Even a pregnant staff member could give emergency assistance if no one else is available, although someone should take over his/her duties as soon as possible.

☞ Following are some guidelines for nursing and medical staff in an emergency.

Cardiac Arrest, Transfer of a Patient to Intensive Care Or to the Operating Theatre.

- Maximise distance and minimise time to reduce radiation exposure. This is important with high dose ^{131}I patients, but not necessary for ^{89}Sr and ^{90}Y patients.
- Strontium-89 and ^{131}I are excreted in the urine. Iodine-131 will also be in saliva, sweat and vomitus. Gown and gloves should be put on as soon as possible, without interfering with the care of the patient. A resuscitation mask should be used instead of an airway or mouth-to-mouth resuscitation.
- Put aside in a plastic bag all material which might be contaminated for later monitoring. This includes linen, airways, masks, endotracheal tubes, urinary drainage bags, etc. but not sharps, which should be put straight into an approved sharps container as usual.
- Call nuclear medicine staff to help with monitoring, decontamination and waste disposal
- Restrict access to the area by other staff, until it has been cleared by nuclear medicine.

Death of a radionuclide therapy patient

- The Nuclear Medicine Department should be notified immediately, and will have to advise on what precautions are necessary. The general principles are the same as for the other emergencies given above.
- The needs of the relatives, local customs, and any legal restrictions on embalming, burial and cremation will have to be considered before the body can be released. The table below gives limits of radioactivity in the body for autopsy, cremation and burial, as recommended by the International Commission on Radiological Protection. (Publication 57: Radiological Protection of the worker in Medicine and Dentistry)

Recommended activity levels in MBq below which no special precautions are required:

Radionuclide	T1/2	Autopsy/ Embalming	Burial	Cremation
^{90}Y	65 hrs	200 [a]	2000 [c]	70 [d]
^{131}I	8 days	10 [a]	400 [b]	400 [b]
^{32}P	14 days	100 [a]	2000 [c]	30 [d]
^{89}Sr	50 days	50 [a]	2000 [c]	20 [d]

[a] Based on contamination hazard.

[b] Based on gamma dose rate at 0.5 m from the body.

[c] Based on bremsstrahlung dose rate at 0.5 m from the body.

[d] Based on contamination hazard assuming all radioactivity is in ash.

☞**Go To** your Workbook **section BRS** and answer **question 27**

Key Points:

In a medical emergency:

- The radiation risk to staff from a patient who has had a **diagnostic** nuclear medicine procedure is negligible.
- The radiation risk to staff from a patient who is having radionuclide **therapy** is very small
- The patient's immediate medical needs must take priority.

Section 3:

Radiation Safety and the Patient

Introduction:

Generally diagnostic nuclear medicine procedures are very safe. They are 'non-invasive', usually involving no more than a small intravenous injection and the discomfort of lying still under the gamma camera.

In order to ensure that your nuclear medicine procedures are safe, you need to understand what the risks are for the amount of radiation used. You should also be able to answer questions from patients who might be anxious about being made radioactive for a little while.

Objectives:

On completion of this section 3 you will:-

- Know how much radiation dose a patient gets from a study.
- Know what precautions to take to keep the radiation dose to an acceptable level.
- Be able to reassure patients in simple, easily understood terms.

Time Check: ⌛

Allow **2 hours** to read and understand everything in this section 3.

📖 Refer to 'Patient Care in Nuclear Medicine' Module 2, Unit 21b for further information and some nuclear medicine textbooks have a section on Patient Care, which you should read now for an insight to the patients' needs.
For example:
(Patient Care) Nuclear Medicine and PET/CT: Technology and Techniques
P.E.Christian, K.M.Waterstram-Rich, Elsevier – Health Sciences Div. 7th edition - 2011

1 Patient Doses in Nuclear Medicine

Unlike radiation workers and members of the public, patients are not protected by legal **limits** on how much radiation they can be given for medical purposes. This is because it is the doctor's responsibility to weigh up the risks against the benefits.

But the other two principles of radiation protection - **justification** and **optimisation** - apply:

- Justification: radiopharmaceuticals should not be given to patients unless there is a reasonable expectation of getting information which is useful for the patient's clinical management.
- Optimisation: radiopharmaceutical activity should be kept as low as possible without spoiling the quality of the image or lowering the diagnostic information of the procedure.

In medical imaging, doctors seem to have reached an informal consensus on what is a reasonable amount of radiation for a diagnostic procedure.

For example, "reference levels" of administered activity for many nuclear medicine procedures are given in Schedule 3 of the UN/IAEA Basic Radiation Safety Standards (1997). These standards are being updated and a revised version is scheduled for 2011.

The doses will depend to some extent on the patient's condition. For example, an acceptable radiation dose for a bone scan in a child with a suspected fracture would be much less than the acceptable dose for a bone scan in an elderly patient with widespread cancer.

You already know that an injected radiopharmaceutical is distributed all over the body, in different amounts in the various organs at different times. As you might expect, individual organs will get very different radiation doses. These organ doses are sometimes quoted as **absorbed dose** (in milligrays or millirads) and sometimes as **equivalent dose.** For the beta and gamma radiations used in nuclear medicine, equivalent dose is numerically the same as absorbed dose, but in units of millisieverts or millirems.

How is it possible to express the "radiation dose" to the patient as a single number? A dosimetric quantity called **effective dose** can be used for this purpose.

Note: Older textbooks describe a very similar quantity called Effective Dose Equivalent. This term was recently changed to effective dose after the book was printed.

Effective dose takes into account the absorbed doses and radiosensitivities of all the different organs of the body. Do not worry about how it is worked out - effective dose values for common nuclear medicine procedures can easily be calculated from data as found in Tables 1, 2 and 3 at the end of this subject unit. Effective dose allows us to compare radiation doses from different nuclear medicine procedures, and from x-rays for that matter.

The effective dose from most nuclear medicine procedures is in the range of 1 to 10 mSv (0.1 - 1 rem). This is comparable to many x-ray procedures. Remember natural background radiation is usually around 2 to 3 mSv/year. Thallium-201 and gallium-67 give higher radiation doses than technetium-99m, mainly because of their longer half-lives. Doses from iodine-131 are even higher, because of its 8 day half life, lots of beta radiation, and prolonged uptake in the thyroid gland.

Go To your workbook **section BRS** and complete the **questions 28 - 30** regarding radioactivity and effective doses, using the data in Table 1 (see end of this unit)

Sometimes it is not necessary to give the 'standard' amount of activity. The obvious case is for paediatric patients. It is necessary to reduce the activity administered to children, not just because they are smaller, but because they are more radiosensitive than adults. But it is important not to reduce the activity too much or there will not be enough counts for a good image, particularly for dynamic and SPECT studies.

Collecting enough counts for a study depends firstly on the amount of activity, and secondly on how long the patient can lie still (which is often the limiting factor with children).

Note: This is taken into account with the recommended pediatric activities

See **Table 2** at the end of this unit. (If you wish, you can convert these values from MBq/kg to μCi/lb to by multiplying by 12.29.)

For simple planar gamma camera studies, one method of calculating paediatric dosage is to reduce the usual adult dosage in proportion to the child's weight. The "standard adult" is a 70kg person. For example, if a child weighs 35kg, then the administered activity would be half the normal adult dose.

2. Keeping doses to an acceptable level.

The following points are worth repeating:

- **The accuracy of dose measurement.** This depends very much on the performance of your dose calibrator. The use, calibration and Quality Control of this very important instrument are covered in Unit 4a of this Module.

  Do you measure all of your syringe doses in the dose calibrator? Write the result on a label, and attach the label to the syringe or lead pot used to carry the syringe.

  Do you check the constancy of the dose calibrator with a long-lived sealed source - every day, on every radionuclide setting you use?

  Do you have any way of checking the accuracy of the dose calibrator with a reference source of known activity?

  Do you know that the dose calibrator should not be used to measure doses of pure beta emitters like ^{89}Sr and ^{90}Y, unless it has been calibrated for these radionuclides in exactly the same type of syringe that you are using to inject? (This is because the dose calibrator is responding to bremsstrahlung from the beta rays from these radionuclides, which emit no gamma rays. The amount of bremsstrahlung is very dependent on the size of the source and the type of container.) It is usually more accurate to calculate the required volume from the manufacturer's calibration data on the label.

- **Use the correct radiopharmaceutical**
  Double check the label on the vial (mix-ups do happen!)

- **Use the correct amount of activity**.
  Resist the temptation to increase doses just to 'speed things up'. There may be some justification if the patient is very sick, or you are very busy with a long waiting list of other patients, but not if it just means the working day finishes sooner and the gamma cameras stand idle.
  Table 2 at the end of this unit gives a range of activities commonly used in Australian practices.

- **Give the correct dose to the right patient.** Always ask the patient his or her name before giving the injection. Don't say "Are you Mr. xxx?" because sometimes the patient does not hear very well and says "yes" anyway. Remember there could be two or more patients with the same surname or family

name booked for a scan on the same day, and be especially careful to sort out which is which.

- **Always check that a female patient is not pregnant or breast feeding a baby, before injecting.** Put posters up in the waiting area warning patients to let staff know if they are pregnant or breast feeding. But don't rely on the posters: ask the patient in private as well, because she may be shy. Before giving therapy doses of ^{131}I, get a pregnancy test done if there is **any** possibility the patient could be pregnant.
- **Keep the camera in top working order.** This includes using the right collimator and peaking correctly for the radionuclide in use. It is also important to make sure that QC procedures are done frequently, and that anything odd is reported to your supervisor immediately and fixed as soon as possible. Obviously, there can be difficulties with getting prompt servicing of cameras.

Reference: Gamma Camera Quality Control will be discussed in Module 4, Unit 4c

3 Assessing radiation risks to patients.

It is useful to have some knowledge about the effects of radiation on humans, and about the magnitude of other sources of radiation to which people are exposed.

Note: The following is an introduction to the **"biological effects of radiation"** Following this unit you should study Unit 2c, Radiation Biology, for more details on the subject.

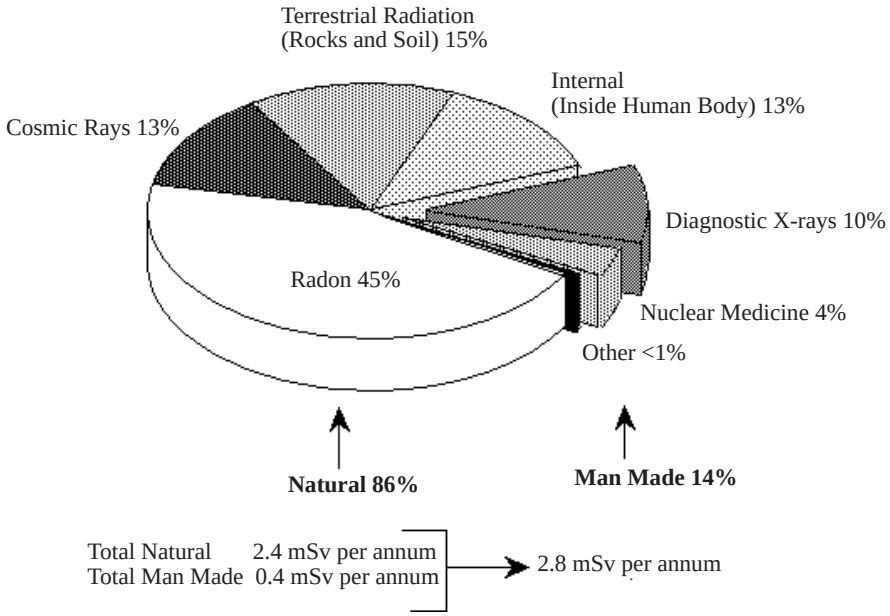


Figure 8

The first thing to realize is that we are all exposed to radiation from 'natural' sources - from the earth and sky, and from natural radionuclides like potassium-40 and carbon-14 in the body. The amount of this background radiation varies from region to region, depending largely on geology. A typical figure would be about 2 - 3 mSv per year. All living creatures have evolved to cope with this level of radiation without any problems. It is well known that the body can repair

radiation damage to some extent, particularly if the radiation is given over an extended period of time.

In addition to natural radiation, populations receive radiation from man-made sources. By far the largest amount comes from diagnostic medical exposures. Figure 8 shows the annual radiation exposure averaged for the world's population. For individual countries, the contribution from medical exposures will vary depending on the level of use of x-rays and nuclear medicine.

It is generally agreed that nuclear medicine diagnostic procedures are 'safe', i.e. the benefits are real and the risk is very small.

In order to make a statement like that, we need to know how much radiation a patient gets from a nuclear medicine study.

Information on dosimetry is given in the package inserts which are included in every delivery of radiopharmaceuticals from commercial suppliers.

Dosimetry values can also be found in ICRP Publications 53 and 62 and ARPANSA Radiation Safety Guide for Nuclear Medicine (Radiation protection Series Number 14.2) [http://www.arpansa.gov.au/publications/codes/rps14_2.cfm] .

You can estimate a radiation dose from data like that in Tables 1 and 3, knowing how much activity was administered to the patient. The actual dose to an individual patient is much harder to estimate. It will depend on their body weight, their age, their physiology (eg. thyroid uptake of iodine) and any disease (eg. poor renal function).

For example,

What is the radiation dose to the bone marrow from an injected activity of 200 MBq of technetium-99m colloid?

Look up ^{99m}Tc colloid in Table 1

Absorbed dose = 200 x 11 = 2200 μGy = 2.2 mGy.

What is the effective dose from the same procedure?

Effective dose = 200 x 9.2 = 1840 μSv = 1.84 mSv.

☞Go To your Workbook **section BRS** and answer the **questions 31 - 32**

The radiation dose to organs and tissues from a nuclear medicine procedure is typically less than 10 mGy, which is a long way below the threshold levels at which body tissues are directly damaged by cell killing or loss of cell function. This type of radiation damage is called **deterministic** damage. The lowest threshold dose for deterministic damage is about 200 mGy to the testes for temporary sterility in males. At doses of about 500 mGy, the lens of the eye and the production of blood cells by bone marrow can be affected. Skin damage may occur at higher doses still, about 1 to 2 Gy.

In fact, the only likely direct radiation damage from a nuclear medicine diagnostic test is skin injury following a faulty injection of certain radiopharmaceuticals. Radiation ulcers have developed at a venepuncture site, months after an unsuccessful injection of thallium-201, when all the radiopharmaceutical was deposited in a small volume of subcutaneous tissue

instead of into the blood stream. So it is important not to force an injection against pressure, because the needle might have come out of the vein.

There is another sort of damage which might occur, even at low doses i.e. perhaps with no threshold. This is when the cell is not killed or its function is not affected, but the genetic material (DNA) in the cell nucleus is damaged. It is called **stochastic** damage.

This can lead to:

i) cancer many years later in the irradiated tissue or organ.
ii) genetic damage passed on to offspring, if the damaged DNA is in germ cells in the ovaries or testes.

It is almost impossible to say exactly how risky a small dose of radiation is, but it is certainly not much. We can ignore genetic disorders in nuclear medicine practice, because the risk is so negligible. There is no evidence of low level radiation causing genetic defects in humans. Even the first generation descendants of the Japanese atom bomb survivors have not shown an increased rate of genetic disorders, to date.

Cancer is a risk that does have to be considered when using radiation. To be on the safe side, we assume that there could be a risk even from very small exposures, although there is no evidence to say so. It is impossible to say exactly how the risk of cancer is related to small exposures, but the ICRP has made an estimate after reviewing the scientific evidence, which shows a correlation for large exposures only.

The ICRP risk coefficient for fatal cancer in adults is 4% per sievert, or about 1 in 2500 from 10 mSv. The risk would be about twice as great in children because dividing cells in young tissues are more radiosensitive. The risk would be less than half as much when people aged over 60 are exposed, because cancer has a long "latent period" of many years - even decades - before it shows up.

Reference: This is discussed further in this Module 2, Unit 2c, Radiation Biology,

☞ **Go To** your Workbook **section BRS** and answer **question 33.**

Pregnant women are a special case, and any request for a diagnostic nuclear medicine study has to be weighed up very carefully. Sometimes the test is not really necessary, when the information can be obtained in other ways.

If the procedure is really thought to be essential:

- Perhaps the procedure can be deferred till later in the pregnancy, after the fetal organs have been formed.
- If possible, avoid all radionuclides except ^{99m}Tc, and keep the radiation dose down by injecting less activity and taking longer to do the scan.

The fetus is sensitive to radiation in two ways.

Firstly, there is an increased risk of childhood cancer. For example, the natural incidence of children dying from cancer in the UK is about 1 in 1300. It is thought that an x-ray or nuclear medicine exposure of 25 mSv to the fetus might

double that risk. A dose of 25 mSv is a rather large exposure for a diagnostic test, but it is possible with abdominal CT x-rays or perhaps big doses of ^{67}Ga and ^{131}I.

On the other hand, a lung scan is sometimes requested to diagnose pulmonary embolism in a pregnant patient. The lung scan should definitely be done, because the fetal dose is very low (less than 1 mSv) and undiagnosed pulmonary embolus can be life-threatening to the mother. However, you should use half the usual activity of ^{99m}Tc.

Secondly, there is an increased risk of congenital abnormalities from an exposure at a critical stage of foetal development. Radiation exposure when the fetus is 8 to 22 weeks old can cause mental retardation, although it probably needs a threshold dose of about 100 - 200 mSv. The fetal thyroid, which starts to concentrate iodine at about the 12th week of pregnancy, can be damaged if it is exposed to iodine-131. **For these reasons, radionuclide therapy or scans using ^{131}I must not be given to pregnant women.**

Precautions for the patient

There are two important cases where you will need to make sure the patient understands the need for some precautions:

1. Breast feeding mothers

If the patient is breast-feeding, the child will receive an internal dose from ingested breast milk in addition to an external dose from close contact with the patient. Advice about the possible need to restrict breast-feeding needs to be given to the patient; this advice will depend on the radiopharmaceutical and its activity, and will ensure that the infant will receive a total effective dose of no more than 1 mSv.

A patient who is breast-feeding a child should be advised of the risks of continued breast-feeding before any therapeutic or diagnostic nuclear procedure. This includes an increased radiation dose to the breasts of the patient as well as the radiation dose to the child.

Table 4 provides a summary of recommendations concerning the requirements for interruption of breast-feeding for some commonly used radiopharmaceuticals. This is based on data collated by Cormack et al (2004), and takes into account both external and internal radiation exposure. As the concentration in the breast milk is highly variable and often differs by at least a factor of 2 between patients the advice in the table is based on a conservative approach. Where appropriate facilities are available it may be preferable to directly measure the concentration of the radionuclide in the breast milk to determine the time at which breast-feeding can resume. The table provides concentrations in kBq/mL below which resumption of breast-feeding will result in a dose of less than 1 mSv. Further information, including details of the computational model and data used, can be obtained from the ANZSNM Web Site (www.anzsnm.org.au)

It is important that breast-feeding be stopped before commencing therapy with any unsealed radionuclide.

Where interruption of breast-feeding is necessary it may be possible to express some milk prior to the study and to store at least one feed in a refrigerator or freezer. The baby should be fed naturally just before the study. During the period of interruption recommended in Table 4, the mother should regularly express and discard her milk. It should be explained that, if this advice is followed, the radiation risk to the infant will be extremely small and will be no more than he/she would receive in a few months from natural background radiation

For ^{131}I and ^{67}Ga, the suspension period is at least three weeks, which could mean the infant has to be weaned**. This is not necessarily best for the baby.** You will need to take the mother's situation into account - will she need help to organize an alternative milk supply, eg clean bottles and a suitable milk formula? It is much better to avoid using these radionuclides if possible.

If the mother needs treatment of hyperthyroidism or thyroid cancer with ^{131}I, then the infant **must** be weaned and breast milk secretion finished before the dose is given. This protects the infant, but also protects the mother from a high radiation dose to breast tissues, which concentrate iodine during lactation.

2. Therapy patients

With patients having large doses of ^{131}I for thyroid cancer, the hazard to others from radiation exposure and radioactive contamination is high enough that the patient must be treated in a special 'isolation' ward, allowing enough distance and shielding to protect patients in nearby beds. The patient must understand the need to restrict visiting by family and friends:

- no pregnant women, babies or children to visit.
- a short stay only by other visitors (say 15 minutes/day)
- visitors should keep 2 -3 metres away from the patient.

The patient should also understand the need for really good personal hygiene:

- daily showers if possible,
- hand washing after every use of the toilet, and
- no splashing of urine to contaminate the floor or toilet.

The patient returns home after ^{131}I treatment, usually 2 - 4 days after the dose. Outpatients treated with a smaller amount of ^{131}I for hyperthyroidism, must still be told to follow simple precautions for two weeks:

- keep up good personal hygiene, particularly with regard to urine,
- keep close contact with infants, children and young adults including pregnant women **to a minimum** (say less than 20 minutes a few times a day). For example, do not sleep in same bed with children or pregnant woman, or cuddle babies for hours.

Key Points:

So what reassurance can you give to patients?

For patients in general, and the rare case of pregnant patients needing a lung scan, you can say that

- the procedure is safe,
- the radioactivity is short lived, and

- the substance in the injection is chosen to give a very low radiation dose.

  It is also safe for their families and close companions. After all, you work with these patients all the time!

💻 **Go to** IAEA **Radiation Protection of Patients** website for further information **LINK**

Table 1 RADIATION DOSE / MBq ADMINISTERED TO PATIENT
For normal 70 kg adult only. Disease states can make a significant difference to dosimetry. Data taken from ICRP Publications 53 and 62.

R'pharmaceutical	Organ Absorbed Dose *μGy/MBq*					Effective Dose *(μSv/MBq)*
	Highest organ dose	**Red Marrow**	**Uterus#**	**Ovaries**	**Testes**	
^{99m}Tc						
Pertechnetate	ULI:62	6.1	8.1	10	2.7	12
Colloid	Spleen:78	11	1.9	2.2	0.6	9.2
HIDA	Gall bladder:110	7	13	20	1.5	15
Phosphonates	Bone surfaces:63	9.6	6.1	3.5	2.4	5.8
DTPA	Bladder wall:65	2.5	7.9	4.3	2.8	5.2
Ceretec	Kidneys:34	3.4	6.6	6.6	2.4	9.3
MIBI	Gall bladder:39	5.5	7.8	9.1	3.8	8.5
MAG3	Bladder wall:110	0.9	12	5.4	3.7	7.3
Aerosols	Bladder wall:47	2.7	5.9	3.3	2.1	6.1
Technegas	Lungs:93	4.1	1.7	1.0	0.6	14
MAA/mss	Lungs:67	4.4	2.4	1.8	1.1	11
Gluconate	Bladder wall:56	3.9	7.7	4.6	2.9	5.4
red cells	Heart:23	7.3	4.7	4.2	2.7	6.6
" " heated	Spleen:560	4.3	1.4	1.4	0.5	19
white cells	Spleen:150	22	3.8	4.2	1.7	11
DMSA	Kidneys:170	6.3	4.6	3.7	1.8	8.7
^{131}I						
Iodide (35%↑)	Thyroid:500 000	86	50	42	26	24000
MIBG	Liver:830	67	80	66	59	140
^{201}**Tl** chloride	Testes:560	180	50	120	560	230
^{67}**Ga** citrate	Bone surfaces:590	190	79	82	57	110

NOTES: Values can be converted to mrad/mCi by multiplying by 3.7

Uterus dose be used to approximate absorbed dose to fetus from r'pharmaceuticals administered to mother in <u>first three months of pregnancy, (assuming no placental transfer)</u>

Table 2: TYPICAL ADMINISTERED ACTIVITIES

Procedure	Radiopharmaceutical		Adults[a]	Children[b]	All[a]
			MBq	Minimum MBq	MBq/kg
bile ducts	^{99m}Tc	iminodiacetates	150	15	2.1
blood pool eg GHPS, liver	^{99m}Tc	red blood cells	800	80	11.4
GIT bleed	^{99m}Tc	red blood cells	400	40	5.7
bone	^{99m}Tc	phosphonates, phosphates	600 (800)	60(80)	8.6 (11.4)
bone marrow	^{99m}Tc	colloid	400	40	5.7
brain	^{99m}Tc	DTPA, pertechnetate,	500 (800)	50 (80)	7.1 (11.4)
brain	^{99m}Tc	Exametazime	500	100	7.1
brain	^{18}F	FDG	400	40	5.7
cisternography	^{111}In	DTPA	30	20	0.4
GIT motility	^{99m}Tc	non absorbable markers	40	10	0.6
Gastric emptying	^{99m}Tc	non absorbable markers	12	1.2	0.2
infection	^{99m}Tc	white cells + HMPAO	200	40	2.9
infection	^{67}Ga	citrate	150	15	2.1
liver	^{99m}Tc	colloid	80(200)	15(20)	1.1 (2.9)
lung perfusion	^{99m}Tc	MAA	100(200)	10(20)	1.4 (2.9)
lung ventilation	^{99m}Tc	Technegas	40	4	0.6
Meckels	^{99m}Tc	pertechnetate	400	40	5.7
myocardium	^{99m}Tc	Sestamibi	300(400)	30/40	4.3 (5.7)
myocardium	^{99m}Tc	phosphonates, phosphates	600	60	8.6
myocardium	^{18}F	FDG	400	40	5.7
myocardium	^{201}Tl	chloride	80	8	1.1
parathyroid	^{99m}Tc	Sestamibi	900	90	12.9
renal scan	^{99m}Tc	DMSA(III)/DTPA/ MAG3	80/300/100	15/30/15	1.1/4.3/1.4
renogram	^{123}I	o-iodohippurate	20	10	0.3
spleen	^{99m}Tc	denatured red blood cells	100	20	1.4
thyroid	^{99m}Tc	pertechnetate	80	10	1.1
thyroid	^{123}I	iodide	20	3	0.3
thyroid cancer	^{131}I	iodide	400	40	5.7
tumour	^{18}F	FDG	400	40	5.7
tumour	^{67}Ga	citrate	150	15	2.1
tumour	^{99m}Tc	Sestamibi/ DMSA(V)	900/400	90/40	12.9/5.7
tumour	^{111}In	pentetreotide	110 (220)	11 (22)	1.6 (3.1)
tumour	^{123}I	mIBG	400	70	5.7
tumour	^{131}I	mIBG	20	20	0.3
tumour	^{201}Tl	chloride	150	15	2.92.1
venogram	^{99m}Tc	pertechnetate	800	80	11.4

a Based on data from RIDIC, BSS, ARSAC and others.

b Minimum activities based on 10% of adult dose (ARSAC criteria) or EANM Paediatric Task Group minimum, whichever is higher.

NOTES: These values are given as a guide only, and may vary according to local techniques and patient needs.

Administered activities for children should be calculated on the basis of body weight, subject to the minima specified.

Reference:

From Ell and Gambhir. Nuclear Medicine in Clinical Diagnosis and Treatment, 3rd ed Vol II

Table 3: Effective doses at various ages from a selection of radiopharmaceuticals.

Radiopharmaceutical	μSv per MBq at Various Ages Effective Dose (E) Conceptus (< 3 mo)*	Newborn	1 y old	5 y old	10 y old	15 y old	Adult (20 +)
^{18}F FDG †	27	430	96	54	35	24	20
^{67}Ga citrate	93	1160	490	300	200	120	100
^{99m}Tc DTPA aerosol	6	52	23	13	9	8	6
^{99m}Tc DMSA	5	86	37	22	15	11	9
^{99m}Tc DTPA	12	30	14	12	7	9	7
^{99m}Tc HIDA/DISIDA	1.3	220	95	54	35	23	18
^{99m}Tc HMPAO (Ceretec)	8.7	120	54	32	19	14	11
^{99m}Tc MAA	3	170	68	37	24	17	12
^{99m}Tc MAG3	18	27	12	13	9	13	10
^{99m}Tc MIBI	15	140	65	42	26	17	13
^{99m}Tc MDP	6.1	63	26	14	9	5.9	4.8
^{99m}Tc pertechnetate $	11	140	62	35	22	16	12
^{99m}Tc RBC in vivo	6	70	31	17	12	7.9	6
^{99m}Tc RBC in vitro	7	71	31	17	12	8	6.1
^{99m}Tc sulphur colloid	2	93	42	23	16	10	8
^{99m}Tc leucocytes	4	200	74	39	25	17	13
^{111}In pentetreotide † #	82	880	380	210	150	110	80
^{123}I iodide	20	2700	1900	1000	470	320	200
^{123}I mIBG	18	150	65	39	26	21	17
^{131}I Iodide	72	283000	206000	107000	47100	30400	18400
^{131}I mIBG	110	1840	710	340	250	200	150
^{201}Tl chloride	97	3650	2080	1340	1010	260	160

NOTE: Values can be converted to mrad/mCi by multiplying by 3.7

* Effective dose to conceptus per MBq administered to mother

$ With blocking agent

† Effective dose to children calculated from H_E values and adult E/H_E ratio

\# Estimated using clearance data from ^{111}In Octreoscan product information (Mallinckrodt Medical)

Reference:

From Ell and Gambhir. Nuclear Medicine in Clinical Diagnosis and Treatment, 3rd ed Vol II

Table 4. Advice to patients concerning the need to restrict close contact with an infant and/or the need to interrupt breast-feeding in order to ensure that the infant receives a total effective dose (from both external and internal irradiation) of no more than 1 mSv. The close contact pattern is that typical of a fretful, sick or demanding infant. The contact time restrictions may be relaxed for a less demanding child.

Radiopharmaceutical	Administered activity (DRL) to mother (MBq)	Advice to patient concerning the need to restrict close contact with child [a]	Advice to patient concerning the need to interrupt breast-feeding [b]	Milk activity concentration below which breast-feeding can resume [a] (kBq/mL)
^{18}F-FDG	400	Not required	1 h interruption	8
^{51}Cr-EDTA	8	Not required	Not required	Not required
^{67}Ga-citrate	400	Restrict contact for 3 days	Cessation	0.3
^{99m}Tc- aerosol or Technegas	40	Not required	Not required	Not required
^{99m}Tc-colloid	200	Not required	Not required	Not required
^{99m}Tc-DISIDA or HIDA	200	Not required	Not required	Not required
^{99m}Tc-DMSA	185	Not required	Not required	Not required
^{99m}Tc-DTPA	500	Not required	Not required	Not required
^{99m}Tc-MAA	200	Not required	13 h interruption	12
^{99m}Tc-MAG$_3$	350	Not required	Not required	Not required
^{99m}Tc-MDP or HDP	900	Restrict contact for 1 h	1 h interruption	1
^{99m}Tc-MIBI	400 rest + 1100 stress	Restrict contact for 4 h	4 h interruption	1
^{99m}Tc-pertechnetate (thyroid)	200	Not required	26 h interruption	14
^{99m}Tc-pertechnetate (Meckels)	400	Not required	34 h interruption	14
^{99m}Tc-PYP	800	Not required	2 h interruption	8
^{99m}Tc-red cells (in vitro or in vivo labelled)	1000	Restrict contact for 2 h	12 h interruption	15
^{99m}Tc-Tetrofosmin [c]	400 rest +	Restrict contact	4 h	1

Radiopharmaceutical	Administered activity (DRL) to mother (MBq)	Advice to patient concerning the need to restrict close contact with child [a]	Advice to patient concerning the need to interrupt breast-feeding [b]	Milk activity concentration below which breast-feeding can resume [a] (kBq/mL)
	1100 stress	for 4 h	interruption	
^{99m}Tc-white cells [d]	750	Not required	24 h interruption	14
^{111}In-octreotide	200	Restrict contact for 42 h	45 h interruption	Not required
^{111}In-white cells	20	Not required	Not required	Not required
^{123}I-MIBG [e]	370	Not required	22 h interruption	0.5
^{123}I-sodium iodide	20	Not required	6 h interruption	1
^{125}I-HSA	0.2	Not required	6 day interruption	0.003
^{131}I-sodium iodide (post-ablation)	200	Restrict contact for 6 h	Cessation	0.0005
^{201}Tl-chloride	120	Not required	15 h interruption	0.22

Notes to Table 6:

a Takes into account external exposure from the patient only. The contact restriction times specified are post-administration (i.e , the time lapse from the time the radiopharmaceutical is administered to the patient to the resumption of normal contact)

b Takes into account both external exposure from the mother and internal dose from ingested milk. The interruption periods specified are post-administration.

c There is a lack of hard scientific data relating to the uptake and clearance of ^{99m}Tc-Tetrofosmin from breast milk. For the purposes of these calculations, it has been assumed that its behaviour in vivo is similar to that of ^{99m}Tc-MIBI.

d Assumes a labelling efficiency of greater than 75%

e Assumes the chemical species appearing in the breast milk is ^{123}I-sodium iodide.

Reference:

From Radiation Protection in Nuclear Medicine. ARPANSA Radiation Protection Series Number 14.2

Radiation Safety and Basic Physics

Glossary:

absorbed dose

Energy imparted by ionising radiations to unit mass of matter. The SI unit of absorbed dose is the gray (Gy),
1 Gy = 1 J/kg.
The non-SI unit was the rad. 1 Gy ≡ 100 rad

activity

The number of nuclear transformations or disintegrations occurring in a quantity of radioactive material per unit time. The SI unit is the becquerel (Bq) which is one disintegration per second. The non-SI unit was the curie (Ci).
37 MBq = 1 mCi; 1 MBq = 27 μCi.

acute exposure

A large dose of radiation received over a short time.

air kerma

A measure of the energy transferred to air from a beam of photons, where kerma stands for '**k**inetic **e**nergy **r**eleased per unit **ma**ss'. Widely used instead of the quantity *exposure*. The SI unit is the *gray*.

ALARA

Acronym for "**A**s **L**ow **a**s **R**easonably **A**chievable", a basic principle of optimising radiation protection to minimize exposures.

alpha particles (or alpha rays)

A positively charged particle emitted in the radioactive decay of some nuclei, e.g. radium. Identical with the nucleus of the helium-4 atom, with a mass number of 4 and a charge of +2. It is strongly ionizing, with low penetrating power and short range. The most energetic alpha particle will generally fail to penetrate the skin. Alpha particles are hazardous if inside the body. Alpha emitting radionuclides are not commonly used in nuclear medicine.

annihilation radiation

Two photons of gamma radiation produced when a positron combines with an electron. Each photon is of energy 0.51 MeV, and they are emitted in opposite directions. Used in Positron Emission Tomography (PET), mainly with fluorine-18.

annual limit on intake (ALI)

For adults working with radioactive materials, the ingested or inhaled activity that will give an effective dose of 20 mSv.

atom

The smallest amount of an element which has the properties of that element. The atom consists of a central nucleus containing neutrons and protons, around which electrons move in orbits.

atomic number

The number of protons in the atomic nucleus , and hence the number of electrons on an electrically neutral atom. Determines chemical properties of element. Symbol Z.

atomic weight

The weight of an atom expressed in atomic mass units (amu). One amu is one twelfth of the mass of a stable atom of carbon, ^{12}C.

attenuation

The process by which a beam of radiation is reduced in intensity when passing through matter. It is the combination of absorption and scattering processes

attenuation coefficient, μ

The negative exponent of the exponential equation for the attenuation of radiation passing a distance x through a substance of density ρ. A fraction μdx of the radiation beam is removed in passing through a thin layer of thickness dx.

If dx is expressed as a length, then μ is the linear attenuation coefficient, usually tabulated in units of cm^{-1}. If dx is expressed as a mass per unit area, then the mass attenuation coefficient μ/ρ is used, tabulated in units of $cm^2.g^{-1}$.

Auger electron

Electron emitted from the atom, after a nuclear transformation by electron capture or internal conversion leaves a vacancy in an electron shell. Some of the resulting *characteristic x-rays* (see below) impart their energy to orbital electrons which are emitted instead. Auger electrons are numerous and low energy.

background radiation

Radiation from the natural environment, including cosmic rays and radiation from the naturally radioactive elements, both outside and inside the bodies of humans and animals.

becquerel (Bq)

The SI unit of activity, equal to one nuclear transformation per second.

beta particles (or beta rays)

A particle with an electric charge of + or - 1, emitted from a nucleus during radioactive decay. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Beta particles are easily stopped by a thin sheet of metal or plastic.

bioassay

The collection and analysis of samples of tissue and body fluids to determine the amount of radioactive material in the body.

biological half life

The time required for the amount of a substance in an organ, tissue or the whole body to be reduced by half through physiological processes of elimination. Does not include reduction through radioactive decay.

Bremsstrahlung

Electromagnetic (x-ray) radiation created during the deceleration of charged particles passing through matter. The main component of diagnostic x-rays. Also associated with the absorption of energetic beta rays from radionuclide decay, e.g. ^{32}P

calibration

A performance check of a measuring instrument by comparison with a known standard, e.g. activity or exposure, to determine the correction factors necessary for accurate use.

characteristic X-radiation

Electromagnetic radiation given off when an atom in an excited state reverts to its normal energy state by filling an orbital electron vacancy with another electron.

chronic exposure

A low dose of radiation received over a long period of time, typically many years.

contamination

The deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or persons.

controlled area

A defined and sign-posted area in the workplace where
(i) access by the public is restricted and measures are taken to control occupational exposures of staff
(ii) measures are taken to avoid unintended exposures and contamination.
See also *supervised area*.

cosmic radiation

Penetrating ionizing radiation, both particulate and electromagnetic, originating in space.

coulomb per kg

The SI unit of exposure, C/kg

counter

A general description of instruments that detect and measure radiation. The signal produced by an ionization event is called a count.

curie (Ci)

The old unit of activity. One curie is 3.7×10^{10} disintegrations per second, i.e. 3.7×10^{10} Bq

daughter products

Nuclides formed by radioactive decay. eg from radium-226 there are 10 successive daughter products, ending in the stable nuclide, lead-206.

decay constant (λ)

The proportion of nuclei in a radioactive source which disintegrate per unit of time. Related to half-life by $\lambda = 0.693 / T_{1/2}$

e.g. if T1/2 = 6 hours, $\lambda = 0.693/6 = 0.115$, so 11.5% of the atoms in a sample disintegrate per hour.

decay, radioactive

Disintegration of the nucleus of an unstable (radio)nuclide, leading to an exponential decrease in the activity with time.

decontamination

The reduction or removal of contaminating radioactive material from a structure, area, object, or person. If incomplete, may be supplemented by isolation during natural decay, or by covering the contamination to attenuate the radiation emitted.

deterministic effects

Radiation damage which occurs above a threshold dose and whose intensity is proportional to the dose. For example, skin erythema, bone marrow depression, cataracts, temporary sterility.

disintegration

A spontaneous nuclear process in which the nucleus of an atom changes its form or its energy state, by emitting charged particles or by electron capture, and/or electromagnetic radiation (x-rays and gamma rays).

dose

The amount of ionizing radiation energy received. See also *absorbed dose*, *equivalent dose*, and *effective dose*.

The term "dose" is also used loosely for exposure in air to a radiation beam, or to the amount of activity administered to a patient.

dose rate

Radiation dose per unit time: e.g μGy/h.

dosimetry

(i) The practical measurement of radiation exposures using various types of radiation instruments (eg personal monitors, survey meters)

(ii) The application of theoretical principles to estimate radiation dose in human tissues.

effective dose

The sum of the equivalent doses in all tissues of the body from a particular exposure, weighted by a *tissue weighting factor,* according to tissue radiosensitivity. Gives an indication of the overall risk of an exposure, independent of the part of the body exposed.

The unit is the sievert, 1 Sv = 1 J/kg.

The non-SI unit was the rem. 1 Sv ≡ 100 rem.

effective half life

The time required for the amount of a radioactivity in an organ, tissue or the whole body to be reduced by half through the combined action of radioactive decay and biological excretion.

electromagnetic radiation (EM)

Energy propagated by oscillating electric and magnetic fields. EM radiations range from x- and gamma radiation of very short wavelength, through the ultra-violet, visible, and infrared radiations, to radar and radio waves of long wavelength.

electron

An elementary charged particle with a unit negative charge and a mass 1/1837 that of the proton. Electrons surround the positively charged nucleus of an atom and determine the chemical properties of the atom.

electron capture (EC)

A mode of radioactive decay whereby the nucleus of the atom captures one of the orbital electrons, usually from the inner (K) shell, leaving the daughter nuclide in an excited state. The atom reverts to its ground state by emitting characteristic x-radiation and Auger electrons.

electron-volt (eV)

A measure of the energy of a particle or EM radiation. It is the kinetic energy acquired by an electron when it is accelerated across an electric potential of 1 volt.

1 eV = 1.602×10^{-19} joules (the joule is the SI unit of energy).

element

One of the 103 known substances that contains similar atoms and cannot be broken down further without changing its chemical properties. Some examples include hydrogen, nitrogen, gold, lead and uranium. Determined by atomic number, Z.

equivalent dose

A modified version of absorbed dose, weighted by a *radiation weighting factor*, to take into account the biological impact of the type of radiation concerned. The unit is the sievert (Sv). The non-SI unit was the rem. 1 Sv ≡ 100 rem.

For the x-, gamma and beta radiations used in medicine, equivalent dose in sieverts and absorbed dose in grays are numerically equal and either can be used for tissue doses.

exposure

A measure of the ionisation produced in air by X- or gamma radiation. The SI unit of exposure is Coulombs per kilogram. The non-SI unit was the Roentgen. See also *air kerma*.

external radiation

Exposure to a radiation source located outside the body.

extremities

The hands, forearms, feet and ankles. Extremity dose limits are less than for the whole body because the extremities contain less blood-forming material and have smaller volume for energy absorption.

film badge

A packet of photographic film used for the approximate measurement of radiation exposure for personnel monitoring purposes.

gamma radiation

EM radiation emitted from atomic nuclei, following various radioactive decay processes. Gamma ray emission may be prompt (immediate) or delayed (isomeric transitions).

Geiger-Mueller counter

A radiation instrument. It consists of a gas-filled tube containing electrodes, between which there is a high voltage but no current flowing. When ionizing radiation passes through the tube, ions are created in the gas and travel to the electrodes causing a short, intense pulse of current. The number of pulses per second is a measure of the intensity of the radiation.
Sometimes called a Geiger counter, or a GM counter.

Gray (Gy)

The SI unit of absorbed dose. 1 Gy is equal to 1 joule per kilogram of the material being irradiated. Doses are usually expressed in the sub-multiples 1/1,000 (milli) and micro (1/1,000,000) of a Gray, ie. mGy and μGy.
1 Gy ≡ 100 rads.

half life, $T_{1/2}$: radioactive or physical

The time required for the activity of a radioactive substance to be reduced by half through radioactive decay. Each radionuclide has a unique half-life.
See also *biological half life* and *effective half life.*

half value layer (HVL)

The thickness of a material which reduces the intensity of an x-ray or gamma ray beam to one half its original value. HVL = 0.693 / μ approximately, where μ is the *linear attenuation coefficient*.

IAEA

International Atomic Energy Agency

ICRP

International Commission on Radiological Protection. The ICRP makes recommendations for radiation protection which are used as a basis for legal controls in many countries

internal conversion (IC)

A process whereby the energy of an excited nucleus may be imparted to an inner orbital electron, which is then ejected from the atom instead of a gamma ray. The internal conversion coefficient is the ratio of IC electrons per gamma ray photon. IC electrons are mono-energetic.

internal radiation

Exposure from radioactive substances in the body.

ion

An electrically charged atom or molecule, i.e. one which has lost or gained one or more electrons. High temperatures, electrical discharges or nuclear radiations can cause ionization. Ions can exist in gases or in solution.

ionising radiation

Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

isomeric transition (IT)

A process whereby an 'excited' atomic nucleus changes from a higher to a lower state of energy, by emitting gamma radiation with a measurable half life. Some of the energy may be removed by the emission of IC electrons instead.

isotopes

Nuclides with the same number of protons (atomic number), but different numbers of neutrons and therefore different mass numbers, e.g. ^{16}O, ^{17}O and ^{18}O are three isotopes of oxygen.

labelled compound

A chemical compound containing a radionuclide. By measuring its radioactivity, a labelled compound (tracer) may be followed through physical, chemical or biological processes.

mass number

The number of nucleons (neutrons and protons) in the nucleus of an atom. Symbol A.

metastable state

When a nucleus is left in an excited state after a nuclear transformation for a measureable length of time. Eventually decays to its ground state *by isomeric transition*.

micro-

A prefix that divides a basic unit by 1,000,000 (i.e. 10^{-6})

milli-

A prefix that divides a basic unit by 1000 (i.e. 10^{-3})

nano-

A prefix that divides a basic unit by 1,000,000,000 (i.e. 10^{-9})

Neutron

An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen.

nuclear disintegration

See decay, radioactive

nuclear energy

The energy liberated by a nuclear reaction (fission or fusion) or by radioactive decay.

nuclear radiation

Particles (alpha, beta, neutrons) or photons (gamma, x-rays) emitted as a result of nuclear reactions or radioactive decay.

nucleon

Common name for a particle of the atomic nucleus. Applies to protons and neutrons but may also include any other particles found to exist in the nucleus.

nucleus

The central part of an atom consisting of protons and neutrons.

nuclide

A species of atom characterised by its atomic number and mass number, e.g. $^{17}_{8}O$, $^{24}_{11}Na$, $^{131}_{53}I$.

Refers to all known nuclides, stable (279) and unstable (about 5000).

parent nuclide

A radionuclide that upon radioactive decay yields a specific daughter nuclide.

periodic table

An arrangement of chemical elements in order of increasing atomic number. Elements of similar properties are placed one under the other, yielding groups or families of elements. There is a general similarity of chemical behaviour within each group.

personnel monitoring

The measurement of radiation exposure of individuals using dosimeters or bioassay.

photon

A quantum (or packet) of energy emitted in the form of electromagnetic radiation. Its energy is equal to $h\nu$, where h is Planck's constant (6.626×10^{-34} J-s), and ν is the frequency of the radiation (s^{-1}).

pico-

A prefix that divides a basic unit by one trillion.

pocket dosimeter

A small radiation detection instrument that indicates radiation exposure directly. May use solid state semi-conductor detector, or gaseous GM or ionization chamber.

positron

A positively charged electron emitted by certain radionuclides. It is unstable, and in combination with an electron it undergoes annihilation to form annihilation radiation.

proportional counter

A radiation detection instrument with a gas-filled detector in which the pulse size is proportional to the incident energy. Can be used as a sensitive contamination monitor for large areas.

protective barriers

Walls and barriers of material such as lead, concrete, plaster, lead acrylic or lead glass. Used to reduce radiation exposure by shielding.

proton

An elementary nuclear particle with a positive electric charge located in the nucleus of an atom. (*See atomic number*)

quality assurance

A comprehensive set of actions or procedures to ensure that all aspects of a service will perform satisfactorily.

quality control

A set of tests routinely performed on a piece of equipment to confirm its satisfactory performance.

rad

The old unit of absorbed dose . 1 rad = 100 ergs per gram.

1 rad ≡ 10^{-2} Gy = 10 mGy.

radiation trefoil

An officially prescribed warning symbol (a magenta trefoil on a yellow background) that must be on or near radiation sources.

radiation weighting factor

A multiplying factor used to weight the absorbed dose from a given type of radiation to obtain the equivalent dose. Radiation weighting factors range from 1 for electrons and photons to 20 for alpha particles and some neutron energies.

radioactive decay

The exponential reduction of the number of atoms in a radioactive source as it undergoes disintegration.

radioactive material

A minimum level (exempt quantity) may be defined by the regulatory body for the purposes of notification, registration, licensing, transport or disposal,
eg. material with a specific radioactivity exceeding 100 kBq/kg and a total radioactivity exceeding 3 kBq.

radioactive series

A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the parent, the intermediate members are called daughters, and the final stable member is called the end product.

radioactivity

The spontaneous disintegration of the nucleus of an unstable radionuclide, generally emitting alpha or beta particles and often accompanied by x- or gamma rays.

radiological survey

Evaluation of the radiation hazards from the production, use or presence of radioactive materials or other sources of radiation under a specific set of conditions. May include a physical survey of the sources and equipment, measurements of radiation exposure and/or air and surface contamination levels, review of personnel monitoring records.

radiopharmaceutical

Any labelled compound used as a pharmaceutical in which the radioactivity is an essential component.

radiosensitivity

The relative susceptibility of cells, tissues, organs, organisms, or other substances to radiation injury.

rem

The old unit for equivalent dose. 1 rem = 100 ergs/g

1 rem ≡ 10^{-2} Sv = 10 mSv

roentgen(R)

The old unit of exposure. 1 R = 2.58 x 10^{-4} C kg^{-1}.

scattered radiation

Radiation that has been changed in direction during its passage through a substance. It may also have been modified by a decrease in energy

scintillation detector or counter

The combination of phosphor, photomultiplier tube, and electronic circuits for counting light emissions produced in the phosphor by ionizing radiation.

secondary radiation

EM or particulate radiation originating from the absorption processes of other radiation in matter.

SI units

The International System of Units. The SI units of activity and absorbed dose, the becquerel and the gray, were adopted in 1975. The old units, the curie and the rad, together with the roentgen and the rem, should no longer be used.

The following prefixes are used to construct decimal multiples of units:

Submultiple	Prefix	Symbol	Multiple	Prefix	Symbol
10^{-1}	deci	d	10	deca	da
10^{-2}	centi	c	10^{2}	hecto	h
10^{-3}	milli	m	10^{3}	kilo	k
10^{-6}	micro	μ	10^{6}	mega	M
10^{-9}	nano	n	10^{9}	giga	G
10^{-12}	pico	p	10^{12}	tera	T

sievert (Sv)

The SI unit of equivalent dose and effective dose. It has the same dimensions as the gray, ie 1 Sv = 1 J/kg.

1 Sv ≡ 100 rem.

somatic effects

Effects of radiation on the exposed individual, as distinguished from *genetic effects*, which may also affect subsequent unexposed generations.

specific activity

Total radioactivity of a given nuclide per gram of a compound, element or radioactive nuclide.

stochastic effects

Effects of low level radiation exposure, where the probability of occurrence depends on the dose. It is generally assumed there is no threshold dose for stochastic effects. Refers to induction of cancer and hereditary defects.

supervised area

An area which is not a controlled area but where radiation safety needs to be kept under review. For example, a waiting area for patients.

survey meter

Any portable radiation detection instrument especially adapted for inspecting an area to establish the existence and amount of radioactive material present.

tenth value layer (TVL)

The thickness of any specified material which reduces the intensity of an x-ray or gamma ray beam to one tenth its original value. Two TVL's will reduce the intensity by a factor of 10 x 10; i.e., 100.

terrestrial radiation

The portion of natural radiation (*background*) that is emitted by naturally occurring radioactive materials in the earth.

thermo-luminescent dosimeter (TLD)

A semi-conductor radiation detector which is capable of storing a fraction of the absorbed ionising radiation and releasing this energy in the form of light when heated at a later time. The amount of light released is a measure of radiation exposure.

For example, CaSO4:Dy for whole body TLD badges, and LiF:Mg,Ti for extremity badges.

tissue weighting factors

Multiplying factors used to weight the equivalent doses to 12 specified tissues and organs before summing to obtain the effective dose. Tissue weighting factors range from 0.01 for skin and bone surfaces to 0.2 for the gonads. A weighting is allowed for other 'remainder' tissues.

Ultraviolet radiation

Electromagnetic radiation of a wavelength between violet light and low-energy x-rays.

unsealed radioactive material

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

whole-body exposure

An exposure of the body to radiation, in which the entire body rather than an isolated part is irradiated.

wipe sample or 'swipe'

A sample made for the purpose of determining the presence of removable radioactive contamination on a surface. It is done by wiping, with slight pressure, a piece of moistened filter paper or other absorbent material over a defined area of the suspect surface.

X-rays

Penetrating electromagnetic radiation of much shorter wavelength than UV or visible light. Result of two processes:

Bremsstrahlung (continuous spectrum to a maximum energy) produced from the acceleration of electrons in the electric field around the atomic nucleus, eg x-ray machines bombard a metallic target with fast electrons in a high vacuum, or when high speed beta particles are absorbed in metal shielding and characteristic x-rays (single energy related to changes in electron vacancies in atomic orbits) emitted as a result of some radioactive decay processes.