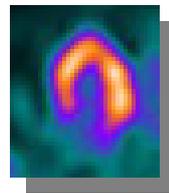
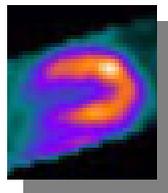
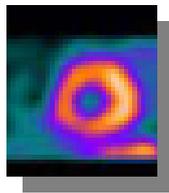


NHS Trust

Nuclear Medicine

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Grade A Training Portfolio



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Competencies

Given here is a list of the competencies specific to the Nuclear Medicine placement and which sections they are covered in this portfolio

Competency	Relevant sections
NM 1.1	1.1, 3.1, 3.2
NM 1.2	1.1, 1.2, 2.1, 2.2, 2.3, 3.1, 3.2, 6.1
NM 1.3	4.1, 4.2
NM 1.4	4.1
NM 1.5	2.1, 2.2, 2.3
NM 1.6	6.2
NM 1.7	5.1, 5.2, 6.2
NM 2.1	1.1, 1.2, 4.2, 4.3, 6.1, 7.2
NM 2.2	1.1, 1.2
NM 2.3	3.1, 5.1, 5.2, 6.2, 7.1
NM 2.4	9
NM 2.5	7.1, 7.3
NM 2.6	8
NM 2.7	8

Department Overview

The Nuclear Medicine department at this hospital is split into two main sections. These are the Imaging section, which is situated in the outpatient clinic area, and the Laboratory section located in medical physics, which is responsible for all non-imaging studies and therapeutic procedures using unsealed radionuclides. The other main department interaction for Nuclear Medicine is the Radiopharmacy department, which supplies the ^{99m}Tc and other radioisotope labelled tracers and drugs required by the department on a daily basis. The department's staff is multi-disciplinary, including consultant clinicians, nurses, medical technical officers, physicists and secretarial staff.

The Imaging section operates three gamma cameras, namely the GE TM Millennium, PhilipsTM Axis and GE TM Maxxus. The first is a single headed camera, whilst the other two are both dual headed systems. The Axis system possesses two Barium sources used to perform attenuation correction of images. The range of imaging studies carried out on these cameras on a regular basis includes renal scans, bone scans, myocardial perfusion imaging studies and lung V/Q scans, as well as less frequent studies such as HMPAO brain imaging, labelled white cell studies and parathyroid imaging. The duration of a study depends on the type of study. Renal scans usually take 20 minutes whilst a solid stomach study can last up to 2 hours. The predominant study type carried out by the department is the bone study. In fact the department periodically runs an out-of-hours service for bone studies on two cameras for an evening. The aim of this clinic is to reduce waiting times for this study. The weekly load can be variable but in a typical week the study schedule may consist of 180 studies including around 49 bone studies, 23 lung V/Q studies (both parts), 17 myocardial perfusion stress studies (10 rest), 21 kidneys studies & 11 GFR injections. This workload along with servicing requirements, QC test schedule and occasional faults experienced by the camera system (temporarily removing them from regular use) means that non-clinical access to the equipment can be difficult at times. In addition to these imaging studies.

Imaging technicians in Nuclear medicine do not wear lead aprons as are worn by technicians in radiology because of the difference in energies of the radiation concerned. X-rays used in radiology have energies of approximately 70 keV while the gamma rays from ^{99m}Tc are 140 keV. The aprons would need to contain four times the thickness of lead to afford the same level of protection. The weight of this amount of lead makes lead aprons in nuclear medicine impractical. Technicians therefore rely on principles of time and distance in limiting their exposures from patients as radioactive sources. The principle of shielding is very important, however, for sources in vials and syringes.

The Laboratory section carries out the non-imaging studies such as ^{14}C urea breath testing for *Helicobacter pylori* and Glomerular Filtration Rate tests, as well as being involved with ^{90}Y , Thyrotoxicosis and Thyroid Ablation targeted radionuclide therapies. These are administered in departments external to Nuclear medicine as well as within the imaging section itself. with any samples taken being analysed in the laboratory section. The typical annual workload for this section includes approximately 400 urea breath tests, 600 GFR investigations 30 blood volumes,

The laboratory section runs a twin crystal counter, two gamma well counters and one beta counter, as well as a number of dose calibrators. The section is also responsible for ordering non-^{99m}Tc radioisotopes and management of the entire hospital's radioactive waste in accordance with the Radioactive Substances Act 1993.

The Nuclear Medicine department also liases with the Radiation Physics department when necessary, such as during the preparation of sources for transport to NPL mentioned in section 7.2 of this portfolio.

1. Quality Control

Quality control tests are carried out on the camera systems, radionuclide dose calibrators and sample counters in the Nuclear Medicine department at a range of frequencies. A sample of the tests that I have observed and carried out is detailed below. The exception to this is the ^{131}I sensitivity calibration of the Axis camera system. While this is part of the quality control carried out in the department it has been included in section 6 of this portfolio. Additionally, quality control tests concerning radiopharmaceuticals have been discussed under the Radiopharmacy in section 4 of this portfolio.

1.1 Gamma Camera Quality Control

Daily Uniformity floods

During my placement in the Nuclear Medicine department I carried out the gamma camera daily floods for a week, setting up the cameras and sources, acquiring the necessary images and reviewing the results under the supervision of a physicist.

The gamma camera detectors' uniformity is checked each morning before the imaging workload commences. The specific procedure is dependent on the system being checked but all work on a similar principle. For all systems in the Nuclear Medicine department the daily floods are performed without the collimators in place. The result is a measure of the intrinsic detector uniformity as opposed to that of the system uniformity. A 20 MBq source supplied by radiopharmacy is positioned at least 5xFFOV (full field of view) from the detector along the central axis perpendicular to the detector face. The iso-surface is a spherical shell but the camera only occupies a small fraction of this shell allowing for the approximation at large separations of the iso-surface as a flat surface with respect to the detector (fig 1.1.1).

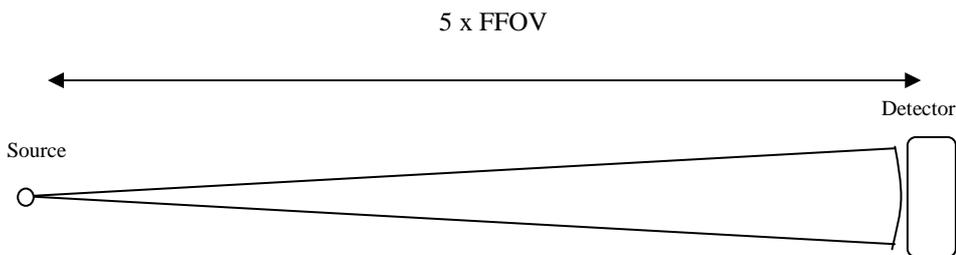


Fig 1.1.1. Schematic diagram of source set up

The GE Millennium camera system has the capacity to perform these floods using a bipod holder, which positions the source above the camera with the detector facing upwards. In this set up the source is much closer to the detector so the iso-surface has a greater degree of curvature. The system applies a mathematical correction to the counts detected to account for the geometry of the surface and detector. However, this method is not adopted by the department due to the weight of the bipod, which makes it unreasonable as a daily method from a health and safety point of view.

An image of the source at 5xFFOV is then acquired over 10 Mcts and the image uniformity analysed. Assuming a uniform flux of incident photons on the detector, the counts received by the camera per pixel should be constant across the detector face.

This analysis comprises integral and differential uniformity values of the CFOV (central field of view) and FFOV.

Integral Uniformity is defined as "...a measure of the difference between the maximum and minimum counts per pixel in the image" [1]. The differential uniformity is a measure of the worst contrast calculated for sets of columns and rows of 5 adjacent pixels in the image.

$$\text{Eqn 1.1}^{[2]} \quad \text{Integral Uniformity} = \frac{(C_{\max} - C_{\min})}{(C_{\max} + C_{\min})} \times 100\%$$

$$\text{Differential Uniformity} = \frac{(H - L)}{(H + L)} \times 100\%$$

In this equation C_{\max} and C_{\min} are the maximum and minimum pixel counts in the image, and H and L are the highest and lowest pixel counts from in the 5-pixel set with maximum difference in counts between two pixels.

The central field of view may be defined as an area in the centre of the detector that has dimensions that are 70% of those of the FFOV, although other definitions exist.

The integral and differential uniformity values are considered to be acceptable, for the Philips Axis system, if they are below 3.5 % & 2.5 % respectively for the FFOV and 2.5 % & 2.0 % respectively for the CFOV. The uniformity acceptance limits are higher for the FFOV due to edge effects. The PMTs within the CFOV are surrounded by other PMTs, which contribute the acquisition of the signal for pixels within that area. PMTs around the outer edge of the FFOV of the camera head are only partially surrounded. By not having the assistance of the additional PMTs, the uniformity in this region can be slightly more variable. High uniformity values would render the gamma camera diagnostically unusable as false lesions may be induced on a normal scan or true lesions may be masked by the non-uniform response of the camera. If the integral or differential uniformity were outside their respective limits for the CFOV or FFOV then the camera status would be evaluated by a physicist. This may lead to the camera's removal from normal use until a reason is ascertained and the fault corrected.

System Uniformity

System uniformity tests are performed on a monthly basis. The test is performed with the collimator in place. A ^{57}Co flood sheet is placed in contact with the collimator and an image is acquired (Millennium ~26Mcts, Axis and Maxxus ~99Mcts). For the dual headed systems the flood sheet is laid on one head with the other head directly above it and both images are acquired simultaneously. The tests are started at the end of a working day and left running over night. The images are then analysed in the same way as the daily floods. While it may be considered more technically correct to use a $^{99\text{m}}\text{Tc}$ flood phantom, as this is the most frequently used isotope, these phantoms require mixing. The process of drawing up the $^{99\text{m}}\text{Tc}$ source, injecting it into the phantom and mixing results in a higher staff dose and use of staff time. They are more likely to be inhomogeneous, if not mixed properly. ^{57}Co is used as a compromise between accurate representation, radiation protection and efficient use of staff time.

Centre of Rotation (Weekly)

The centre of rotation QC test is performed weekly on a 3 week rotation basis between the 3 camera systems. The Axis camera system uses a different method to the Millennium and Maxxus systems. The latter two use a 30 MBq syringe of ~0.02 ml pertechnetate as provided by the radiopharmacy. The syringe is attached to a metre rule, which is fixed to the couch in order to position the source in the centre of the field of view axially and vertically, but off centre laterally. The metre rule is used to allow the source to overhang the couch. This is to minimise any attenuation of the source when imaged by the detector heads when below the source. The Axis system uses a jig with three wells, which are loaded from a syringe containing 900 MBq of ^{99m}Tc -pertechnetate. Each well holds 1.5 ml and the jig is loaded with approximately 700 MBq of ^{99m}Tc -pertechnetate, depending on concentration of the source.

The system is then set to take images at 60 positions over 360° around the source. As the camera moves around the source its position in the x-axis, X, varies. Fig 1.1.2 shows the ideal variation of x with detector angle, Θ . The difference between this ideal plot and the actual plot obtained gives the performance of the machine.

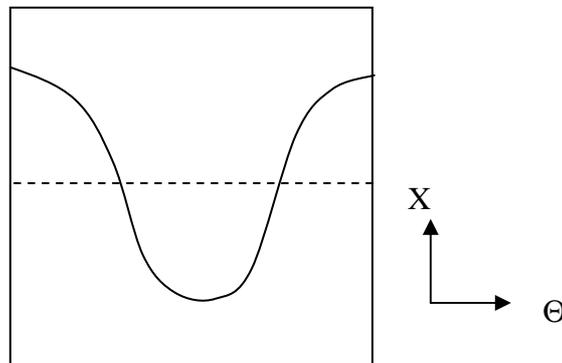


Fig 1.1.2 Schematic of sine curve of X co-ordinate variation with Θ .

The software fits the function given in equation 1.2 to the actual curve.

$$\text{Eqn 1.2} \quad X = A + B \sin(\Theta + \Phi) \text{ [3]}$$

Where:

A, B and Φ are constants.

Θ is the angle of the detector.

A is the location of the centre of rotation of the camera.

B is the offset of the source from the centre.

The displacement of A from its expected position is calculated in millimetres and recorded. If the displacement is greater than 1 mm, then the camera is removed from use in SPECT imaging until adjustments can be made to correct the problem.

Shell Phantom

The Shell phantom contains a number of randomly distributed “wells” and “blocks” employed to simulate “hot” and “cold” lesions. These are manifested as greater and lesser depths of source along the axis perpendicular to the surface of the detector. The phantom is shown schematically below (fig 1.1.3).

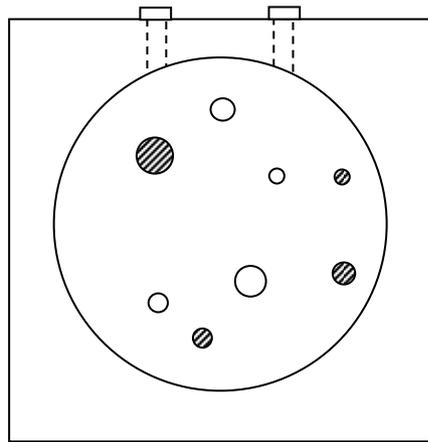


Fig 1.1.3 Schematic diagram of the Shell phantom showing hot and cold spots.

During quality assurance tests carried out during my placement, the phantom was filled with distilled water and a 100 MBq source of ^{99m}Tc was added. ^{99m}Tc is used in most of the QC testing of the gamma cameras, as it is the most commonly used isotope in imaging carried out by the cameras. The mixture was shaken thoroughly to ensure a uniform distribution. The phantom was then imaged by positioning the camera head facing upward and placing the phantom on the collimator (LEGP and LEHR used in turn). The phantom was imaged with 16 Perspex sheets, used to represent scatter, in 2 different configurations. This involved changing the number of sheets above and below phantom. The phantom was imaged for each collimator with 1 sheet below and then all 16 sheets below the phantom with the remaining sheets above the phantom in each case, for 1000 kcts. Hard copies were made of the acquired images, which were then viewed with a light-box to determine which were the smallest observable hot and cold lesions under each set of conditions. This provided a qualitative measure of the resolution of the system.

Contrast Phantom

This phantom was used to evaluate, qualitatively, the minimum contrast that can be confidently observed by the gamma camera system. The phantom is rectangular in cross-section and contains ordered rows of blocks of varying thickness and cross-sectional area. The phantom is shown schematically in fig 1.1.4. Again, the phantom was filled with distilled water, a 100MBq source of ^{99m}Tc was added and the mixture was shaken thoroughly to ensure uniform distribution. The phantom was then imaged in the same configurations as for the Shell phantom. The lowest contrast observable and the lowest contrast at which the smallest lesion was observed gave the absolute minimum contrast and the minimum size dependent contrast for the camera. The images were acquired over 1000 kcts.

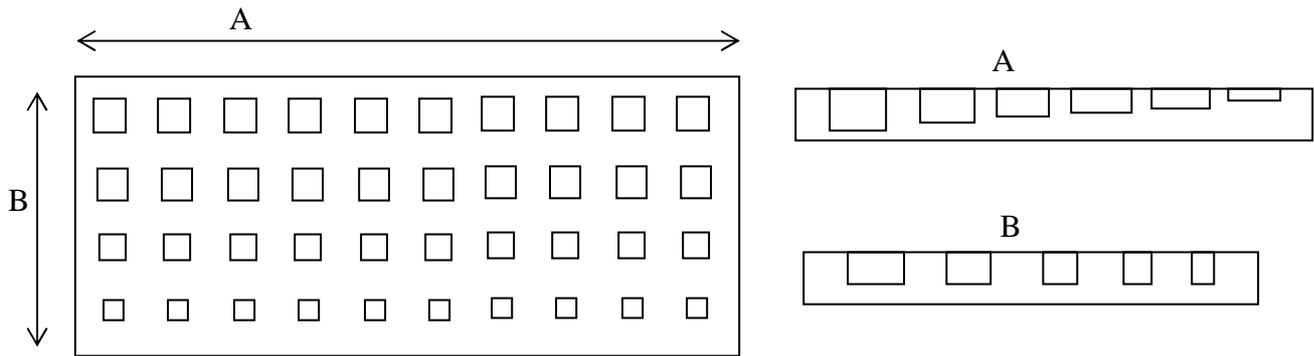


Fig 1.1.4 Schematic diagram of contrast phantom showing variation in cross-section and thickness in profiles along A and B.

Bar and Anger

The Quadrant Bar and Anger Pie phantom tests are qualitative resolution tests. The Bar phantom is a circular lead phantom divided into 4 sections. These sections are transparent to gamma rays. The sections contain lead bars of 4 different widths. The width of the bars within a quadrant is constant and the bars are separate by distances equal to bar width. The Anger Pie phantom is a circular lead phantom divided into 6 sections, each section containing holes of a given diameter.

At This hospital, the set up depends upon the camera being tested. All set-ups involve positioning of the Bar or Pie phantom onto the detector without the collimator in place and irradiating it with a source placed at a distance from the detector, along its central axis. A static image is acquired for a number of counts. The aim is to collect 1000 kcts within the part of the image relating to the phantom. The images are then inspected. In each case, the section containing the smallest resolvable bar spacing or hole size is determined. This gives a qualitative line and point resolution.

Parallel Line Equal Separation Phantom:

System Spatial Resolution & Linearity Testing Of Millennium Camera

During my placement I carried out the following quality control test, under the supervision of another physicist, on the Millennium gamma camera system. The system spatial resolution of the gamma cameras is carried out on an annual basis as part of the department's quality assurance programme. Test uses a PLES (Parallel Line Equal Space) phantom. This phantom consists of five glass capillary tubes held at equal separations in a 30 cm x 30 cm Perspex frame. The bores of the capillary tubes are 30 cm long, ~0.5 mm in diameter and their centres are separated by 60 mm.

The phantom was prepared by filling the capillaries with $^{99m}\text{TcO}_4$ injected from a 2 ml syringe via a 25 gauge needle. The source was 400 – 500 MBq in 1.2 ml in a 2 ml syringe. Once filled, the capillary tubes were sealed at each end with Blutak. The activity, date and time were noted on the phantom. The total activity in the phantom was 100MBq. This information was not used in any of the calculations in the test but was noted to inform others that the phantom was active. Capillary filling was carried out over two drip trays (one at either end) in case of any spills or leaks. Gloves were monitored at the end of each fill to check for any spills due to handling of the syringe while injecting and changed immediately if they were found to be "hot". At this point the phantom contained five uniform line sources. In fact air bubbles were discovered in two of the capillary tubes upon imaging but the regions containing liquid source

were in themselves uniform. The camera was set up with the camera facing upward and the LEGP (low energy general purpose) collimator in place. The phantom was imaged with the line sources orientated along the x-axis and then the y-axis with 0 cm Perspex sheets below and 6 cm on top of the phantom. Images were acquired for 3000 kcts using a 512 x 512 matrix. The phantom was then imaged again with 2.4 cm below and 3.6 cm above in each orientation. 6 mm thick sheets of Perspex were used. The Perspex is needed to simulate different amounts of scatter experienced by photons originating at different depths within a patient. The LEGP collimator was then changed for the LEHR collimator and the phantom imaged in both orientations with both Perspex configurations. The result was 4 images for each collimator.

Using the imaging software regions of interest (ROIs) can be taken perpendicularly across each of the lines on the image to produce a count profile across the line like that shown in fig 1.1.5 The full width at half maximum (FWHM) is deemed to be the width of the profile and was calculated manually from the profile data for 4 points along the first line of the phantom for LEGP and low energy high resolution (LEHR) collimators in place using the method described in fig 1.1.5 The system's software can also be used to calculate the FWHM of a line in a region of interest automatically. This capacity was used to obtain the FWHM from 4 points over 31 pixels on each line in the phantom in both orientations, in both of the Perspex scatter configurations, using both collimators. The width of each profiled region was necessary to obtain a minimum of 10000 counts in the peak pixel. The FWHM values from the 4 ROIs for each line were averaged to give the mean FWHM for the line under each condition. The software also gives the pixel location of the centre of the peak in each ROI. The plotting this data against the location of the ROI and applying a linear fit to the resulting plot allows the evaluation of the linearity of these centroids. Assuming that the line sources themselves are straight, the R^2 of the linear fit gives a measure of the linearity of the system. These sets of data are summarised in tables 1.1.1 & 1.1.2.

Table 1.2.1. FWHM and centroid linearity correlation data for LEGP collimator.

Phantom Orientation	No. of Sheets	Line	Mean Line FWHM	Mean Phantom FWHM	CLC*
X	0	1	5.06	4.87	1.00
X	0	2	4.86		1.00
X	0	3	4.69		0.03
X	0	4	4.78		0.78
X	0	5	4.98		0.99
X	4	1	6.19	6.06	1.00
X	4	2	6.00		0.49
X	4	3	6.04		0.02
X	4	4	5.96		0.06
X	4	5	6.12		0.51
Y	0	1	5.04	4.84	0.99
Y	0	2	4.86		1.00
Y	0	3	4.52		0.98
Y	0	4	4.77		0.99
Y	0	5	5.02		1.00
Y	4	1	6.19	6.07	0.99
Y	4	2	5.97		0.99
Y	4	3	6.04		0.99
Y	4	4	5.98		0.99
Y	4	5	6.19		1.00

*Centroid Linearity Correlation

Table 1.1.2. FWHM and centroid linearity correlation data for LEHR collimator.

Phantom Orientation	No. of Sheets	Line	Mean Line FWHM	Mean Phantom FWHM	CLC*
X	0	1	4.47	4.19	0.99
X	0	2	4.18		0.99
X	0	3	3.84		0.97
X	0	4	4.13		0.98
X	0	5	4.35		1.00
X	4	1	5.21	5.04	1.00
X	4	2	4.96		0.99
X	4	3	4.79		0.11
X	4	4	5.04		0.99
X	4	5	5.19		1.00
Y	0	1	4.44	4.27	0.45
Y	0	2	4.25		0.34
Y	0	3	4.04		0.74
Y	0	4	4.20		0.93
Y	0	5	4.41		0.24
Y	4	1	5.19	5.03	0.99
Y	4	2	5.04		0.70
Y	4	3	4.73		0.55
Y	4	4	4.98		0.97
Y	4	5	5.23		0.99

*Centroid Linearity Correlation

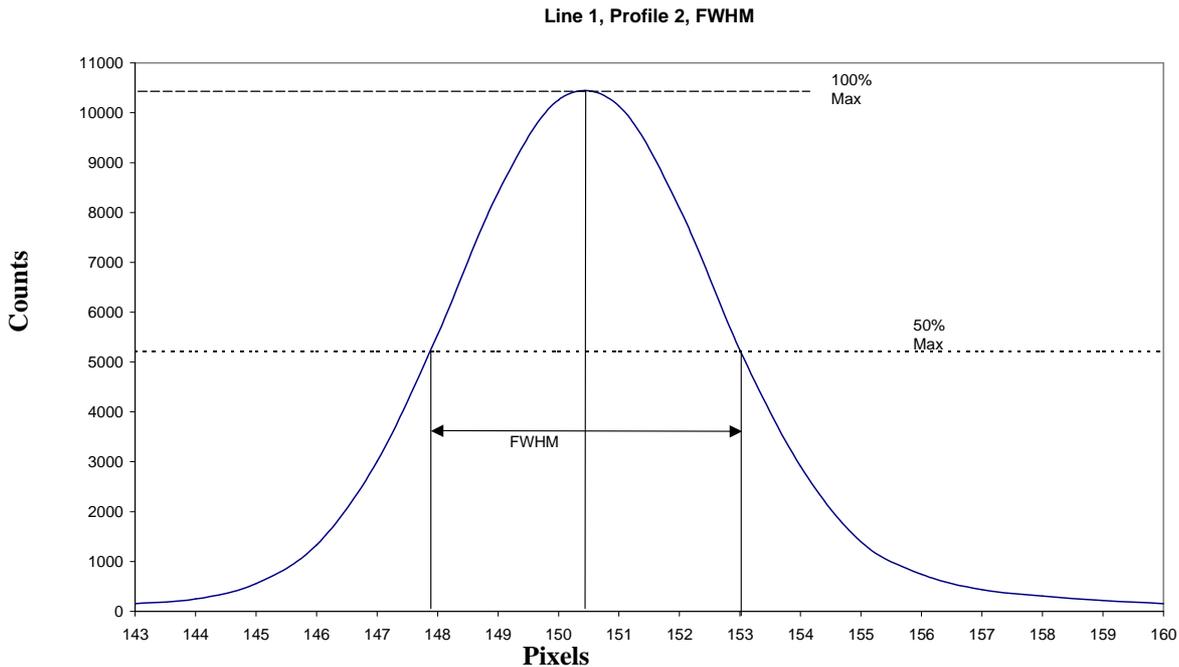


Fig 1.1.5 Shows profile no. 2 of first line of phantom orientated along x-axis with 0-sheets below phantom using LEGP collimator.

The mean FWHM for line 1 was calculated manually as 5.01 pixels for LEGP and 4.37 pixels for LEHR orientated along the x-axis with 0 sheets below the phantom. These correspond to values of 5.06 and 4.47 pixels respectively from the software.

The mean FWHMs of the system were converted to mm using the mean line separation in mm (manual measurement) and pixels (from above data) for LEGP and LEHR collimators as shown in tables 1.1.3 & 1.1.4 respectively.

Axis	Perspex	MLS (pixel)	MLS (mm)	mm/pixel	FWHM (pixel)	FWHM (mm)
Y	0	52.75	60	1.14	4.87	5.54
Y	4	52.77	60	1.14	6.06	6.89
X	0	52.76	60	1.14	4.84	5.51
X	4	52.71	60	1.14	6.07	6.91

Table 1.1.3 LEGP FWHM (mm). MLS – Mean Line Separation

Axis	Perspex	MLS (pixel)	MLS (mm)	mm/pixel	FWHM (pixel)	FWHM (mm)
Y	0	52.74	60	1.14	4.19	4.77
Y	4	52.70	60	1.14	5.04	5.73
X	0	52.99	60	1.13	4.27	4.83
X	4	53.00	60	1.13	5.03	5.70

Table 1.1.4 LEHR FWHM (mm). MLS – Mean Line Separation

Note that here that “Axis” refers to the system resolution coordinates not the orientation of the lines in the phantom. X-axis line orientations give Y-axis FWHMs. The values given in tables 1.1.3 & 1.1.4 correspond to the system resolution in each axis under the specified conditions.

Conclusions

Firstly FWHM values for both sets of results were seen to increase with increased thickness of Perspex below the phantom. Increased FWHM translates to decreased resolution of the system in this configuration. This is due to scatter of the photons by this medium between the phantom and collimator.

Secondly smaller FWHM values were observed with the LEHR collimator than with the LEGP collimator. Although this means this collimator gives a higher resolution it is at the expense of sensitivity of the system. High-resolution collimators use longer and/or narrower holes than low-resolution collimators. This narrows the acceptance angle of incident photons to the cameras NaI detector crystal. It also means that fewer photons reach the detector to produce the image. This leads to a lower signal-to-noise ratio. Therefore to achieve the same quality of image a higher activity dose is required. In the interests of dose optimisation (IRMER 2000, see section 8) LEHR collimators are only used when high-resolution images are necessary for the study.

The wide range in R^2 values for trend lines fitted to the centroid versus region plots was noted. This was brought to the attention of the supervising physicists in the Nuclear Medicine department and suggested that the experiment be repeated in order to check the validity of these results.

1.2 Calibrator linearity test

The calibrators in the nuclear medicine department play a vital role in the department's adherence to the regulations of IR(ME)R 2000 by determining the doses administered to patients. Without adequate quality control of the calibrators patients could receive a dose that is in excess of that required for the procedure or that is insufficient to yield diagnostically useful information. The patient would receive a dose that was not optimised for the study, as required under IR(ME)R2000.

The calibrators must have a linear response to activities of a radionuclide measured. Linearity tests are carried out for ^{99m}Tc on an annual basis. During my placement in the nuclear medicine department I performed a linearity check upon one of the laboratory section's calibrators. The test is based on the comparison of measured activities of a single source with calculated activity values by radioactive decay correction over time.

A 4 GBq source was ordered from the radiopharmacy referenced to 9.00 a.m. on the Monday of the week of the test. The source was collected and measured in the calibrator 3 times and a note made of the time and date. Further sets of measurements were made at various times throughout the course of this and the following 4 days, each time noting the date and time of measurement. The source was kept in a lead pot and manipulated with tongs when measured in the calibrator. When not in use it was stored behind a lead shield in a fume cupboard.

The activity of a radioactive source can be given by the equation 1.3 the expected activities could be calculated for each measurement time.

$$\text{Eqn 1.3} \quad A(t) = A_0 e^{-\lambda t}$$

Where: A_0 = initial activity

$$\lambda = \ln 2 / T_{1/2}$$

$T_{1/2}$ = Half-life of nuclide

t = time

Rearranging equation X.1:

$$\text{Eqn 1.4} \quad \ln A(t) = -\lambda t + \ln A_0$$

A plot of the natural log of A(t) versus time should be linear. In this way, plotting the natural log of the measured A(t) values against time and assessing its correlation to a linear fit will yield a measure of the linearity of the calibrator.

The calibrators may give activity measurements that are not equal to the expected activity while still having a linear response. This is a proportional response drift. This may be accounted for by comparing the logs of measured and calculated activities and assessing the percentage difference between the two at times of measurement. A proportional response drift would be corrected during a Secondary Standard Calibration, in which the dose calibrator is referenced to the primary standard at NPL (section 7.3)

Results

The graph shown in figure 1.2.1 shows that the response of the calibrator was found to be linear. Comparison with the expected data showed a mean percentage difference of 0.29 % and a maximum of 0.53 %. (Note these are based of the moduli of the calculated percentage differences)

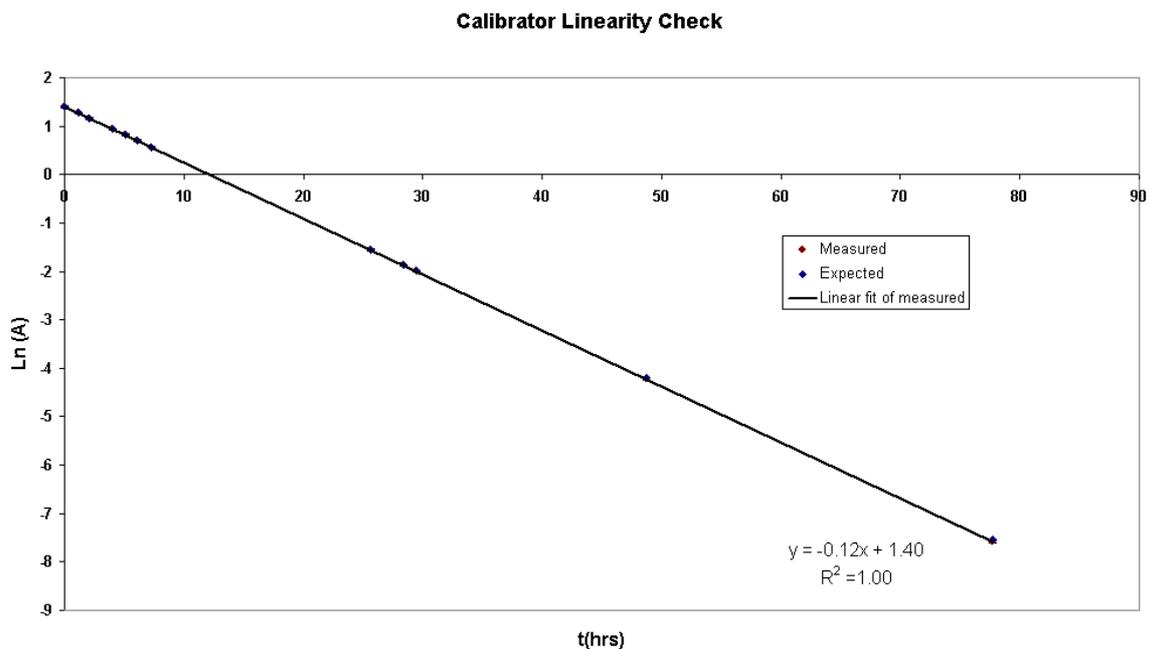


Fig 1.2.1 Plot of $\ln A(t)$ versus time showing linearity of calibrator.

Errors

The error associated with each activity measurement made using the radionuclide calibrator is $\pm 2\%$ ^[14]. As each activity was taken from the mean of three measurements the error then becomes, $\pm 1.2\%$. By calculating the maximum and minimum values of $A(t)$ and taking their natural logs, the absolute errors for each value $\ln A(t)$ could be found. These absolute errors found to be ± 0.02 for each value.

Conclusion

The calibrator's response is sufficiently linear over the range of activities used within the department.

2. Imaging

During my placement in nuclear medicine I observed the preparation of patients, acquisition of images and reporting sessions for patients undergoing a range of imaging studies. In addition I also had the opportunity to carry out the image acquisition procedure (not including tracer administration) for several bone scan patients under the supervision of a technician. This included brief explanation of the procedure to the patient, positioning of the patient and set up of the camera system, commencement of the acquisition itself and contouring of the camera head to the profile of the patient. (Note that contouring is performed during acquisition on the Maxxus system (on the fly) and prior to acquisition on the Axis system). The following describes three of the imaging study types observed.

2.1 Bone Scans

Introduction and Background

Bone scans are generally a planar imaging technique that maps osteoblastic function throughout the skeletal system. Studies carried out at This hospital use ^{99m}Tc -labelled methylene diphosphonate (^{99m}Tc -MDP), which is incorporated into the bone matrix by osteoblasts in bone. MDP binds to calcium hydroxyapatite ($\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$), which is used by osteoblasts with collagen in formation of bone matrix ^[4]. Areas of uptake on a bone image therefore indirectly represent areas of osteoblastic activity in the skeleton and blood flow.

Osteoblastic function goes on throughout healthy bone. Increased osteoblastic activity, as compared to the normal adult, can arise from a number of causes. Normal bone growth in children is seen in the growth plates at the ends of the long bones. It is necessary for a reporter to be aware of this. Increased activity is also seen following trauma to the bones such as breaks or fractures, as well as in degenerative disease and in the sites containing bone tumours. In each of these cases increased uptake results from the process of bone repair. The reporter must compare the normal patterns against the patterns acquired to look for abnormal uptake from these causes.

It is important to note that nuclear medicine bone scans do not image the tumour directly but rather the effect that their presence has. A tumour within a bone can have destructive effect on the material surrounding it, causing increased osteoblastic activity in an area enveloping the tumour. The advantage of nuclear medicine bone scans is this increased osteoblastic function occurs at an early stage in the disease. This allows the presence of a tumour (usually a metastasis) to be detected by the function of the metastasis itself before it can be seen structurally using other imaging modalities such as x-ray or CT. The disadvantage, however, is that while bone scans have a high sensitivity they have a low specificity.

As already mentioned, increased osteoblastic activity is not limited to the presence of metastases, but a range of other causes. As a result bone scans are used as one of a set of investigations. They can be requested for detection of primary tumours, querying prosthesis loosening or infection, diagnosis of infection related bone disease (blood pool images), diagnosis and evaluation of degenerative disease, as well as the staging of cancer originating from known primary tumours causing metastases in bone ^[5].

Interpretation of bone scans is based on patient history and knowledge of typical patterns of increased uptake. X-ray images may be required to further investigate the cause of increased activity in the bone scan.

Scan procedure

The exact procedure depends upon the subject of the investigation and the query posed by the referrer, but all involve the injection of 600 MBq^[i] of ^{99m}Tc-MDP followed by acquisition of static, anterior and posterior, planar images of the patient over the area in question 3 hours post injection. In the majority of cases, the area imaged is the whole of the skeleton, referred to as a “Whole Body Bone Scan”. The length of the scan itself is dependent on the size of area to be scanned. If it is larger than the area of the FOV then the patient is set up with the upper limit of the area near the top of the camera. The length of the area along the axis of the patient is measured and entered into the control computer. The computer then moves the patient under the camera at a given rate while acquiring the images, resting over the superior and inferior limits of the area for a period of time to allow sufficient data to be acquired from these regions. All bone scans use LEHR collimators. Static images are acquired using 256 x 256 imaging matrix while whole body bone scans use a 256 x 1024 matrix.

Referrers can request a “Triple phase” bone scan. In these types of study the static images taken at 3 hours post injection are termed the “static” phase of a bone scan study. The other two phases are the dynamic (or vascular) and blood pool phases. For dynamic phase the patient is positioned with the particular area of interest (e.g. ankles, pelvis, wrists, etc.) between the camera heads (for dual headed system) prior to tracer administration. A sequence of images is then taken at 2 s intervals over a specific area of interest, starting as the tracer is injected. This sequence illustrates the vascularisation of the area by observation of the flow of tracer in its first two minutes of passage through the blood stream. The number of images in this sequence depends on the particular area involved. This is followed by the blood pool phase after approximately 5 minutes. Here a single set of images (1 anterior, 1 posterior) is acquired for 3 minutes or 1000 kcts (which ever is reached first), demonstrating the degree (if any) of blood pooling in the area by observation of the accumulation of tracer within this area. As incorporation into the matrix by osteoblasts takes much longer than the time frame between injection and blood pool image acquisition, any increased tracer retention within an area in these images is due to blood pooling. The addition of the other two phases does not affect the activity administered, but only increases the number of scans performed. An adult bone scan therefore has a fixed effective dose of 3 mSv^[9].

The patient is requested to attempt bladder emptying just prior to the scan, as tracer that is filtered by the kidneys will accumulate in the bladder. This would appear on a scan as a large focus of tracer, which could overlie the pelvis masking any true defects. The patient is also asked to drink more fluids as this promotes soft tissue clearance of the tracer. The result of this is to decrease the background counts from soft tissue in the images, thus increasing the signal to noise ratio.

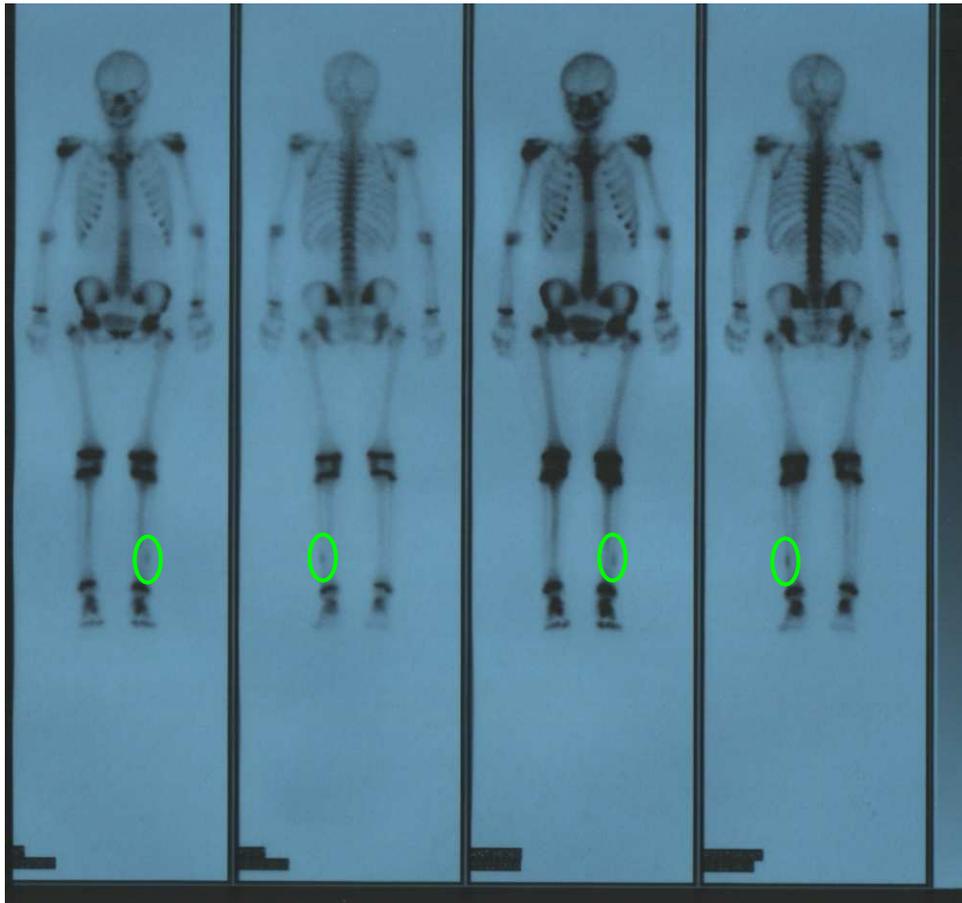
ⁱ The administered activity and effective dose quoted are for adult patients and are scaled according to the Administration of Radioactive Substances Advisory Committee (ARSAC) scale for paediatric patients (age < 18 yrs) according to weight.

Interpretation and Artefacts

The standard approach to interpreting bone scans is to look for areas of abnormal uptake and then compare with the immediate surrounding tissue and the same site on the opposite side of the midline. If an area of increased uptake is mirrored bilaterally then it is likely to be a normal variant. This accounts for normal bone growth but is not an answer in itself and additional factors must be considered. High spot uptakes in the joints may be due to degenerative disease. It is very important to have a sufficiently detailed relevant patient history present when reporting to allow the consideration of all possible causes and the elimination of unlikely causes based on known patient information. As has already been suggested, care needs to be taken when interpreting and reporting bone scans not to be misled by normal bone function and artefacts. The most common artefact observed in bone scans is the appearance of foci of increased tracer uptake over the lower ribs. While these can appear to be the result of metastatic cancer they are often found to be due to the superposition of tracer in the kidneys, which underlie the ribs. If the kidneys are seen to underlie the ribs the clinician may decide to dismiss these foci (based on evaluation of the rest of the image). If he or she is unsure as to whether the kidneys are the cause of these foci, and the patient is still present, a drop kidney image may be performed. In this situation the patient is re-imaged in the region of the kidneys whilst sitting upright. The kidneys are pulled downwards by gravity away from the ribs cage. If the foci are still present in the ribs on the drop kidney then they are real otherwise they are artefactual and may be ignored. Another factor in artefact production is the geometry of the patient's positioning during acquisition. A rotation of the patient about the axis from the true supine position can induce areas of marked increased tracer uptake in the iliac bone of the raised side in comparison to that of the lower side. This apparent difference is caused by the fact that the upper iliac bone is simply closer to the head of the camera. A simple check method for this type of artefact is to study the position of the sternum in relation to the thoracic spine. In the true supine position the sternum should overlie the thoracic spine.

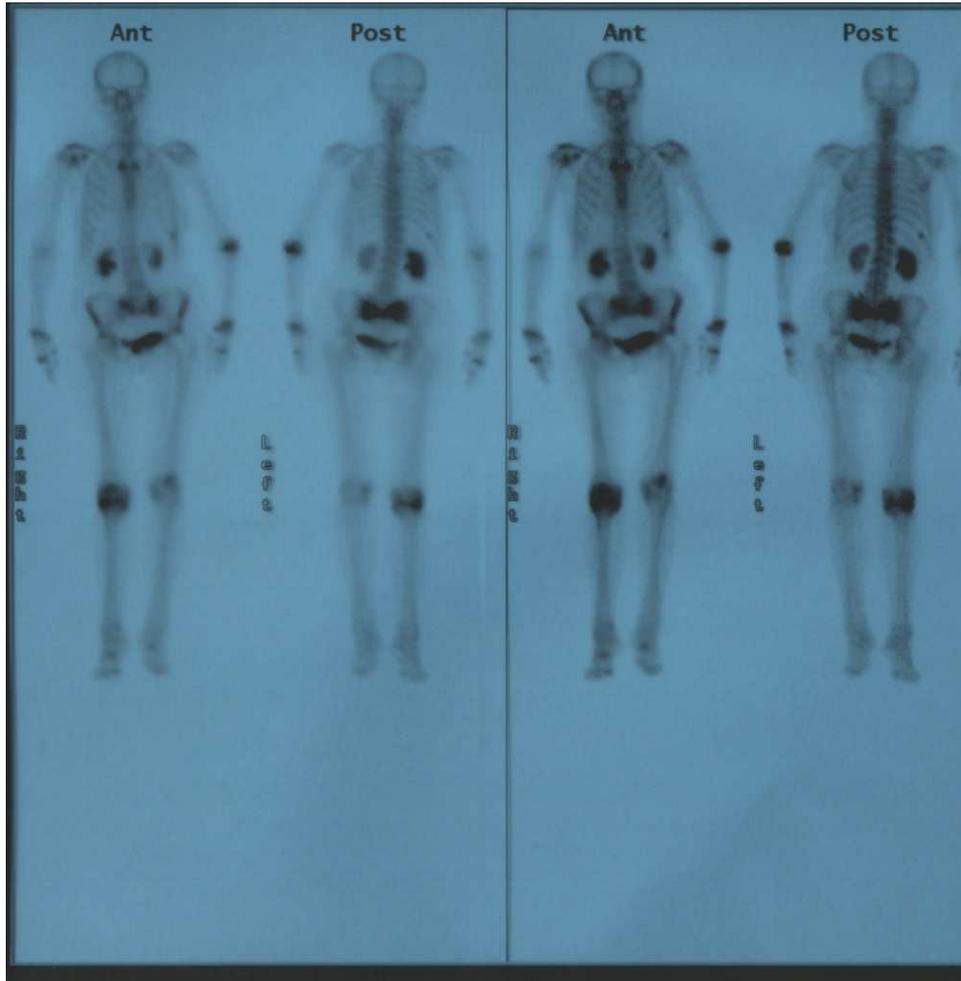
Three patient cases are given below which give represent three distinctly different conditions seen in bone scans. They also show good examples of features, which can lead to misinterpretation.

Case 1: *Study Image 1*



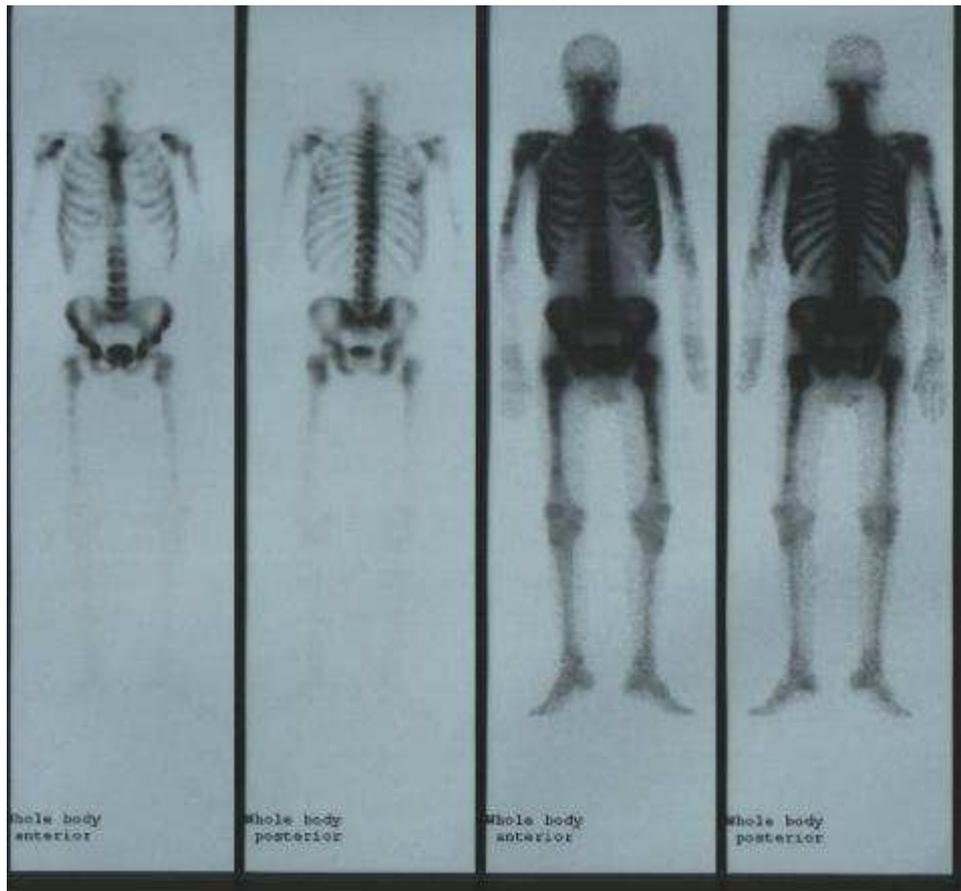
A twelve-year-old female patient presented with pain to the left fibula for three weeks and a palpable mass in the same location. An X-ray of the area showed a destructive lesion. The patient was referred to the nuclear medicine department for a bone scan to determine whether this was a primary bone tumour. Initial observation of the bone scan images in study image 1 show increased uptake in the ends of the long bones, pelvis and nasal cavity. If viewed without reference to the patient details supplied, it could be considered that this patient showed indications of extensive degenerative or metastatic disease. However this pattern of tracer uptake is within normal limit for a patient of this age, who is still growing. The feature of interest in these images is the ellipsoid of increased tracer uptake in the lower half of the left fibula. An area of increased uptake in the tibiae of a physically active patient could possibly be explained by shin splints or stress fractures, however these do not occur in the fibulae. The lack of history of trauma leads to the remaining conclusion that the lesion is probably a primary tumour. The most common childhood bone tumours are primary tumours and leukaemia. Secondary tumours are very rare, which, with the fact that uptake throughout the rest of the skeleton is normal, rules out the possibility of metastatic disease.

Case 2: *Study Image 2*



An eighty four year old female patient presented with marked pelvic pain, which was aggravated by movement and relieved by rotation. The patient had a long-standing history of rheumatoid arthritis and a fall 2 years previously. Plain films showed no abnormalities. The patient was referred for a bone scan to query the presence of fractures. Increased tracer uptake was observed in the left elbow, both wrists, both hands and the right knee as well as in the both sacral-iliac (SI) joints, both superior pubic rami and the sacrum itself. Whilst increased uptake in the SI joints can be indicative of metastatic disease, the simultaneous involvement of the sacrum with the SI joints and the pubic rami gives an uptake pattern that is typical of osteoporotic insufficiency fractures. The pattern of the SI and sacrum is characteristic of this condition and has (on account of its shape) been nick-named by some clinicians as the “Honda sign” for its similarity to the insignia used by the car company. The other features described are typical of degenerative disease in those sites, which is in keeping with the patient history. It is also interesting to compare the normal joints in the images from this patient with those of the patient in case 1. From this comparison the importance of patient information is even more evident when it is considered that these particular joints are normal in spite of the obvious differences between the uptake patterns.

Case 3: *Study Image 3*



This case is particularly interesting as it demonstrates that what cannot be seen is sometimes more important than what can be seen. This patient was referred for a bone scan to query the presence and extent of bony metastases from a known prostate cancer. Initial inspection of the images shows no obvious areas of increased tracer uptake, which would lead to the conclusion that the scan is normal. However if the image is inspected more closely it is apparent that the long bones, skull and kidneys cannot be seen. All of these structures are usually present on bone scans. Their absent indicates that the signal from the visible skeleton (the axial and proximal ends of the long bones) was so high that in order to view the axial skeleton properly, the technician processing the images needed to set the windowing (intensity scale) sufficiently low, as to result in the loss of the skull etc. from the images. This means that far from being normal, the entire axial skeleton demonstrates a large increased tracer uptake. This type of scan is termed a “Superscan” and indicates extensive disseminated metastatic disease throughout the axial skeleton. In this case not considering what was not present in the image could have resulted in a gross under reporting of the patient’s condition.

Note on image display

Nuclear Medicine studies produce digital images. These are arrays of pixels that make up maps of count numbers. The imaging software uses lookup tables to assign colour or intensity values from a scale to each pixel based on that pixel’s count value. The most commonly applied scale is from black to white through different intensities of grey. Each scale can incorporate 256 different colour/intensity scale values.

The human eye is not capable of distinguishing this many different shades of grey. It is useful to set different upper and lower count values of the scale when applying it to the image. Any pixels with values outside of these limits will be assigned the minimum or maximum scale value appropriately. This action extends the number of colour scale values applicable to the count range between the limits. Therefore any small differences in count rate will have a greater colour scale difference, making it more visibly noticeable. This process is called windowing and can affect images and their interpretation.

It is important to note that whilst the colour/intensity scale can be linear with respect to pixel counts, it may be otherwise. A high degree of specificity between count values in the lower regions may not be necessary, therefore a non-linear scale may be used which only applies a small increase in colour/intensity over large count increases in this range. This leaves a larger selection of scale values that can be applied to pixels in the count range of interest.

2.2 Myocardial Perfusion Imaging (with Tetrofosmin)

Observed preparation, imaging, image processing and reporting.

Introduction

Myocardial perfusion imaging (MPI) at this hospital is routinely carried out as a tomographic technique used for imaging and evaluating the blood supply to the left ventricle of the heart at rest and stress. It can be used diagnostically to determine the likelihood of the presence of coronary artery disease in patients with chest pain or as an evaluation tool for patients with known coronary problems.

MPIs are used in relation to suspected coronary artery stenosis (coronary artery disease) to evaluate patients with abnormal exercise treadmill test results. Patients exhibiting reversible ischaemia are then candidates for angiography to locate the vessel causing the problem. For patients who have had a stenosis diagnosed by angiography, MPI investigations can be used to show whether the stenosis has had any effect on myocardial blood flow.

Additionally, a patient with a known history of heart disease scheduled to undergo surgery may have a myocardial perfusion scan performed to evaluate the condition of the myocardium. If the patient has significant areas of inducible ischaemia then they are at risk of suffering further myocardial infarction. It is interesting to note, however, that a patient with extensive infarcted tissue but no inducible ischaemia has a lower risk of myocardial infarction than a patient with normal, healthy myocardial tissue.

Patient preparation for stressed imaging

The normal procedure in the department is to first ask the patient to state their name, address and date of birth. This helps to ensure that imaging and administrations are carried out on the correct patients. The patient's height, weight and chest measurements are then taken along with their blood pressure and heart rate. The patient is injected with dipyridamole, followed 4 minutes later with 400 MBq of ^{99m}Tc labelled Tetrofosmin. The dipyridamole is a vasodilator. Dilation of the vessels causes the patient's blood pressure to fall. The body responds by increasing the rate and strength of the heart's contractions to raise the blood pressure. In this way the dipyridamole is a substitute for exercise to induce stress conditions in the heart.

Principles of Imaging

Tetrofosmin is taken up by the myocardium (amongst other organs) from the blood. For myocardium to take up the tracer it must have a blood supply. The acquisition of a tomographic image (SPECT) of tracer distribution therefore indicates the level of perfusion of the tissue and hence status of blood supply to tissues throughout the heart. The nature of SPECT imaging allows the data to be reconstructed in orthogonal planes defined by the user during post-image processing. Each of the major walls of the left ventricle are visible in two of the planes summarised in the table in fig. 2.2.1. Acquisition of perfusion scans in states of stress and rest allow the clinician to compare the myocardial blood supply in these states. Areas of reduced up take (perfusion defects) that appear at stress but are not present at rest are indicative of inducible ischaemia. A basic system of analysing the images is given in a flow chart in fig. 2.2.2 below.

There are a few key points to remember when reporting these images. Firstly any possible defects should be confirmed on slices in two planes. Secondly, it is easy to “over-report” myocardial perfusion images, true defects should be quickly observable. Some clinicians believe that a study should take no longer than 30 seconds to be inspected by an experienced nuclear cardiology clinician. The third important consideration is that of the contribution of attenuation to a study. The attenuation of gamma rays from any one location is the same at stress and rest for a single patient provided that set-ups for the two scans are consistent. In this way the patient is his or her own control. Therefore any differences between stress and rest perfusion images are not artefacts of differences in attenuation, however, fixed defects must be considered carefully. Reduced uptake on the inferior or anterior walls that are matched in rest and stress images may not be due to infarction of the tissue in that region, but may be due to attenuation of the gamma rays by the patient themselves. Inferior wall attenuation is a factor in male patients who may have thick diaphragms while anterior wall attenuation is a particular consequence for female patients with large breasts. This hospital also use chest bindings to minimise the attenuation in such patients by flattening the breast tissue. As a result the photons have to travel through less tissue before leaving the patient.

Some gamma camera systems have the capacity to perform non-uniform attenuation correction (NUAC). At This hospital this involves the acquisition of images using external barium (^{133}Ba , half-life 10years) sources with the patient in position and without the patient. The software then performs a subtraction to determine the attenuation coefficients of the patient at each location on each image and applies a correction to the image. It should be noted that the practice at This hospital is not to report Tetrofosmin studies from the attenuation corrected images alone. These tend to be used to evaluate fixed inferior and anterior wall defects in the appropriate patients. This is because attenuation correction has been known to induce artificial defects or mask true defects in other areas (see fig 2.2.3). NUAC is currently only available on one of this hospital’s Nuclear Medicine department’s gamma cameras. An alternative method for assessing whether a fixed inferior wall defect is a non-uniform attenuation artefact, where attenuation correction is not available, is to acquire an additional set of rest images with the patient lying prone on the couch. This causes the patient’s heart to move so that the inferior wall moves away from the diaphragm. If the fixed defect seen in the supine images remains in the prone images then the defect is real and tissue is probably infarcted. If it is not present in these images then the defect is an attenuation artefact and may be ignored. This method is reliant on sufficient free camera time being available to acquire the prone images.

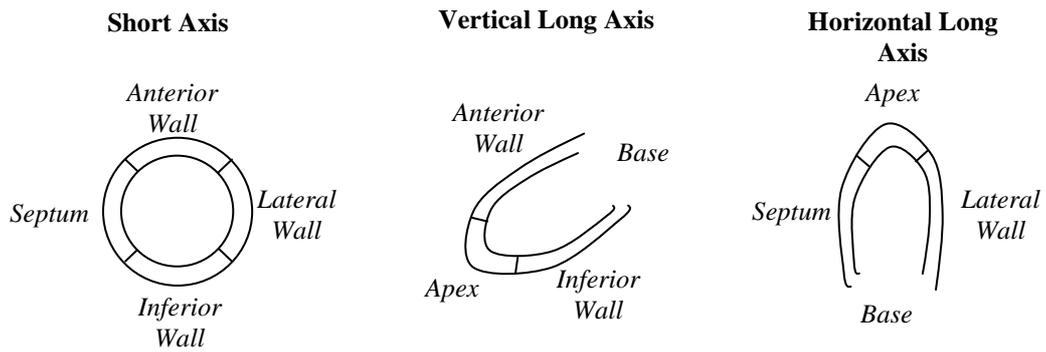
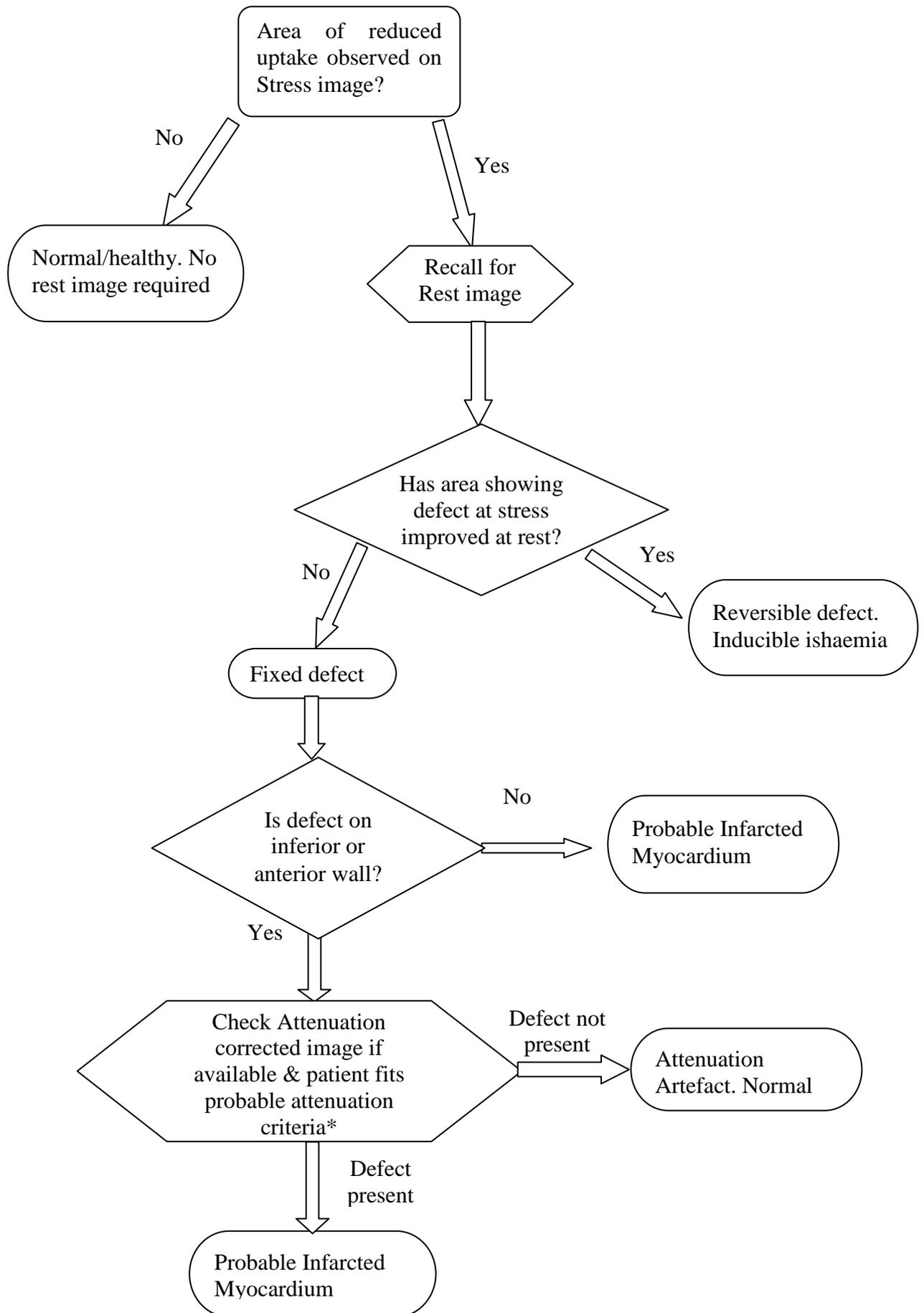


Fig 2.2.1 Structures viewed in the three planes of a myocardial perfusion SPECT scan.

The images in fig. 2.2.3 show an inferior wall defect. The study in this case only has stress images, it is not known whether this defect is fixed or not but has been assumed as such for the purposes of demonstration. The upper set of images are the normal stress images and the lower set show the non-uniform attenuation and scatter correction images. The inferior wall defect in normal stress image is not present on the attenuation-corrected images (V Long Axis Frames 22-24 in STRESS and NUAC, STRESS sequences). At the same time defects are introduced onto the anterior wall in the NUAC images that are not present in the uncorrected images (frames 21-23).

Fig. 2.2.2 Flow chart of image interpretation of myocardial perfusion study



*Attenuation artefacts more likely in, but not exclusive to large male / large-breasted female patients.

Fig 2.2.3 Stress images, corrected and uncorrected for non-uniform attenuation



2.3 Lung Ventilation/Perfusion Imaging

V/Q scans are used in the diagnosis of Pulmonary Embolism (PE). PE is a physical condition in which a blood clot, usually originating from deep vein thrombosis (DVT) in the lower limbs, becomes lodged in a branch of an artery in the lungs, cutting off the blood supply to a section of the lung. PE, if diagnosed early enough, can be treated with anti-coagulants, which help to break up the clot and more importantly to prevent future PE events. This can occur naturally in patients without treatment, but if the clot is not broken down, the affected area of the lung can become damaged and eventually infarcted.

Ventilation Agent

The development of high repeatability in particle size production, desirable half-life and good retention in the lungs has led Technegas[®] to become used in the many departments.

The department at this hospital uses Technegas[®], which is a system that prepares a mixture of ^{99m}Tc labelled carbon particles in an argon gas in two stages. In the first stage a ^{99m}Tc-pertechnetate dose is simmered in a crucible at a few hundred °C to evaporate the water, leaving dried ^{99m}Tc. The second stage heats the dried ^{99m}Tc to approximately 2500°C in pure argon to produce small, solid, ^{99m}Tc labelled carbon particles [6]. These particles are deposited in the alveoli of sections of the lungs, which are ventilated. Isotope distribution in the images acquired therefore show poorly ventilated areas of the lungs as areas of reduced activity. It has been observed that the clearance rate of Technegas[®] from the lungs is very close to that of the physical decay of the ^{99m}Tc itself [7].

Both perfusion and ventilation scans use the low energy general purpose (LEGP) collimators.

Ventilation Scan Details

The Technegas[®] generator is loaded with 400 MBq of ^{99m}Tc-pertechnetate, which is then heated to produce Technegas[®]. The patient is positioned sitting upright on the couch, in front of the camera. The patient is asked to breathe through a mouthpiece and tubing, maintaining a seal around it with their lips. The gas outlet tube of the generator is connected to the mouthpiece tubing. A gas dose is released into the breathing apparatus and the patient is asked to take a deep breath and hold it for 3 seconds. The dose is halted during the breath hold. The patient is then asked to breathe in and out 5 times through the mouth piece. These five breaths are carried out to clear any residual Technegas[®] from the mouthpiece and prevent unnecessary contamination of the room when the patient removes the mouthpiece. This delivery is repeated until the count rate of the camera reaches 1.5 – 2 kcts/sec. The patient then lies supine while the camera acquires images for 200 kcts at angles of approximately 0°, -45°, 45°, -135°, 135° and 180° about the patient to obtain the anterior, right & left anterior oblique, right & left posterior oblique and posterior views. On dual headed systems, the camera heads can acquire opposing views simultaneously, reducing the acquisition time.

Perfusion Scans

Perfusion scans carried out in this hospital use in intravenous injection of 100 MBq of ^{99m}Tc -Macroaggregated Albumin (MAA). The particles in this tracer are cleared from the blood on their first passage through the pulmonary arterial circulation. The mechanism of their retention is a purely physical one. The particles are too large to pass through the arterioles in the lungs and undergo microembolization ^[8]. This first pass clearance means that tracer retention is proportional to blood flow and therefore can be used to assess blood supply to the areas of the lungs. The patient is injected then placed supine on the couch and images taken at the same orientations as for the ventilation scans up to 500 kcts.

Interpretation

PE is typically represented on V/Q scans as a defect on the perfusion images, which is not matched on the ventilation images. A matched defect can be indicative of an infarcted area of the lung. This is not always the case though and the appearance of a true PE event is dependent of the time delay between the event occurring and the time of acquisition. It should be remembered that V/Q scans have a high sensitivity for PE but low specificity. A defect in the images can occur from other causes such as pulmonary effusion. It is the practice of the department to request the patient's chest x-ray with all V/Q scan requests. PE does not appear on a chest x-ray, and an abnormality that appears on the x-ray will most probably cause an abnormal V/Q scan. A V/Q scan on a patient with an abnormal chest x-ray could therefore be non-diagnostic as it might not be possible to distinguish whether the abnormal V/Q was due to a true PE event or the due to the cause of the chest x-ray abnormality.

The effective doses of the two parts of a V/Q scan are 0.6 mSv and 1 mSv for ventilation and perfusion respectively ^[9]. The practitioner must therefore have all relevant information before deciding whether or not the scan is justifiable. The reporter must also have this information available for his/her interpretation of the scan to be valid.

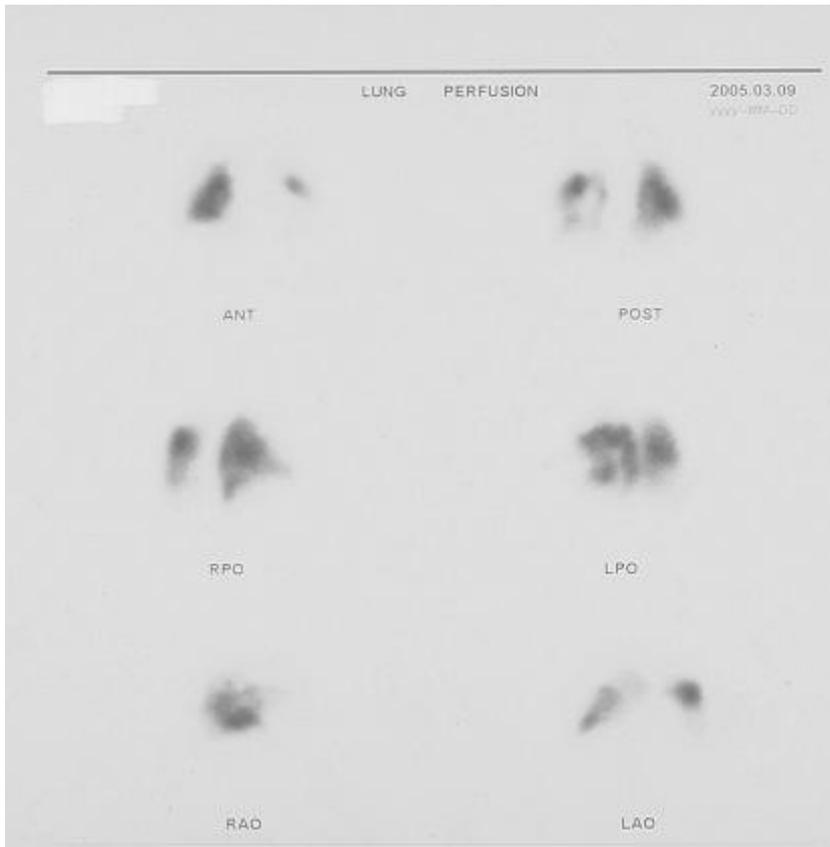
There are four levels of reporting for V/Q scans. The first is "normal" meaning there is no evidence of PE in the images. The other three levels are in terms of probability of the presence of PE and these are "low", "intermediate" and "high".

One pattern constituting a "high" probability report includes multiple defects on the perfusion scan that are not matched on the ventilation scan, accompanied with a clear chest x-ray. An example of such a set of ventilation and perfusion images are shown in fig 2.3.1 and fig 2.3.2.

Fig 2.3.1 Lung Ventilation Image



Fig 2.3.2 Lung Perfusion Image showing multiple defects not matched Ventilation image



3. Laboratory Section

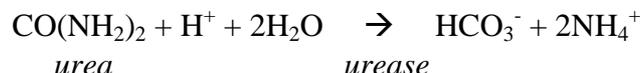
The laboratory section of the Nuclear Medicine department is responsible for the ordering and storage radioactive material, the disposal of radioactive waste, performing non-imaging diagnostic studies and administering radionuclide therapies. Two of the most common non-imaging studies have been described below.

3.1 ¹⁴C-Urea Breath Test (BTU)

The BTU is a test performed to detect the presence of *Helicobacter pylori* (*H. pylori*). *H. pylori* is a bacterium sometimes found in the mucous lining of the stomach. It is not currently known how *H. pylori* is contracted, but once in the stomach it survives the acidic environment by secreting an enzyme called urease that neutralises the surrounding acid. This defence allows the bacterium to reach the protective mucous lining of the stomach, which it burrows into. This environment protects the *H. pylori* from the gastric acids and the immune response as the white cells and T-cells have difficulty in penetrating the mucous lining. The bacterium is thought to be the cause of some peptic ulcers. It weakens the mucous lining allowing gastric acids to come into contact with and irritate the lining of the stomach. Irritation is also caused by the bacterium itself. This irritation causes an ulcer to develop on the lining.

Part of *H. pylori*'s defence mechanism involves the conversion of urea into ammonia by secreted urease according to the equation 3.1.1 given below.

Eqn 3.1.1



The bicarbonate circulates in the bloodstream and is transported to the lungs where is expelled in the form of carbon dioxide. This production of carbon dioxide is the basis of the BTU.

Test details

The pharmaceutical is made up using 5 µg of ¹⁴C-labelled urea, 100 mg of non-radioactive urea (i.e. ¹²C-urea) and 8 ml of water in a 50 ml capacity, brown medicine bottle. The activity of the dose administered is 185 kBq. The patient is fasted for at least 12 hours before the test. They are then asked to brush their teeth with water before being given 200 ml of 2 % citric acid solution orally followed by the urea. Bacteria in the mouth may cause an early peak of CHO₂ in the test. If *H. pylori* is present in the stomach, then the urea will be processed. ¹⁴C-labelled carbon dioxide (¹⁴CO₂) will be produced, carried in the bloodstream and be expelled in the patient's breath.

Twenty minutes after administration of the dose the patient is asked to blow out via a mouthpiece through a solution of 2 ml thymolphthalein and 2 ml of hyamine hydroxide in a vial. Both are clear solutions in isolation and produce a blue colour when mixed. The hyamine hydroxide captures the 2 mmol of CO₂ in the patient's breath. Sufficient CO₂ will have been captured when the hyamine hydroxide has been neutralised. The thymolphthalein is an indicator, which changes from blue to clear

when the pH of the solution is neutral. Therefore the end point of the test occurs when the solution changes colour.

A second breath is collected 40 minutes after administration. A control breath test is carried out prior to administration to account for presence of naturally occurring ^{14}C in the breath. 10ml of scintillant is added to each of the sample vials. The vials are then placed in a β -sample counter and the counts per minute (CPM) are counted along with two backgrounds and two standards. The programming in the counter then applies corrections for counting efficiency due to geometry, photomultiplier tube (PMT) efficiency, quench etc. thus converting CPM that the counter sees to disintegrations per minute (DPM) i.e. what the activity in the sample is actually believed to be. The counts are background corrected and expressed as a percentage of the administered dose applied to the following equation (eqn 3.1.2).

$$\text{Eqn 3.1.2} \quad (\% \text{Dose} \times \text{Kg}) / \text{mmol CO}_2$$

If the two post urea breaths show a significantly higher activity than the control then it may be assumed that $^{14}\text{CO}_2$ has been produced from the ^{14}C -labelled urea. This indicates the presence of urease in the stomach and therefore implies the presence of *H. pylori*. The test classification criteria are given in fig 3.1.1.

Test Classification	Test result, X, (%Kg/mmol)
Negative	$X < 0.5$
Equivocal	$0.5 < X < 1.5$
Positive	$X > 1.5$

Fig 3.1.1 BTU classification criteria

Examples of positive and negative results have been included in figs. 3.1.2 and 3.1.3.

According to the National Institute for Diabetes and Digestive and Kidney Diseases (NIDDK) the BTU has been found to be 96 – 98 % accurate in the indication of *H. pylori* being present.

In the case of a positive test patients will usually undergo triple phase treatment. This consists of 2 antibiotics and an acid suppressor.

The urea breath test, while useful, is not the only test available for the detection of *H. pylori*. It is in fact one of four tests, the others being blood, stool and soft tissue test biopsy.

Neither is the ^{14}C breath test the only available labelled breath test. A similar test may be carried out using ^{13}C -labelled urea instead. Being an isotope of carbon, it will react, chemically, in the same way as the ^{14}C -labelled urea. The major difference occurs in the analysis of the collected carbon dioxide. As ^{13}C is non-radioactive it cannot be detected using nuclear medicine methods. Its relative abundance may,

however, be detected using a mass spectrometer (due to difference in atomic mass to ^{12}C) or by magnetic resonance spectroscopy (due to the fact that ^{13}C has a spin of $I = 1/2$). The ^{13}C BTU is therefore a direct rival of the ^{14}C BTU. While a ^{13}C BTU does not present the radiation hazards of the ^{14}C BTU, which would seem to make it the better option of study in keeping with the legislation concerning radioactive studies (using non-radioactive alternatives to where available to keep patient exposure as low as reasonably practicable) the ^{14}C BTU is more the widely used method owing to the higher availability of beta counters than mass spectrometry equipment in hospitals. The effective dose associated with the ^{14}C BTU is in fact very low at $0.02 \text{ mSv}^{[9]}$, which is equivalent to a few days natural background. ^{13}C tests are also more expensive than the ^{14}C BTU.

Safety

The ^{14}C nucleus decays by low energy β -particle emission. As these particles are rapidly attenuated and unlikely to produce any significant Bremsstrahlung radiation, the medicine bottle containing the urea did not require any lead shielding. Gloves were still worn, however, as a precaution against contamination.

Fig 3.1.2

Fig 3.1.3

3.2 Glomerular Filtration Rate (GFR) Measurement

Function of the kidneys

Blood enters the kidneys via the renal arteries and then passes through the segmental, arcuate and interlobular arteries before entering the glomeruli via the afferent arterioles. The glomerulus is a capillary net ending in the efferent arteriole and is enveloped by Bowman's capsule. The first stage of renal filtration occurs when the blood passes through the glomeruli and the plasma is filtered across the filtration membranes of the structure into Bowman's capsule^[10]. Subsequent stages of filtration and re-absorption occur in the proximal and distal tubules and loop of Henle. The term glomerular filtration rate (GFR) refers to the volume of filtrate produced by the glomeruli per minute. Normal adult GFR values are given later in equations 3.2.5 & 3.2.6.

The definition of what constitutes renal failure, with regard to GFR, varies greatly. Some class any GFR below the normal (or expected) value as being renal failure. What is more important is what represents a significant failure. In this context a good indicator is the point at which creatinine levels begin to rise, as a fall in renal function will not ordinarily be noticed until this point. This occurs when the GFR falls by approximately 40% of the normal. Renal physicians, however, will not usually begin dialysis until a GFR of 25 ml/min is reached. Patients undergoing chemotherapy will have their GFR monitored more closely and their chemotherapy doses will be adjusted depending on the GFR. This is because a low GFR results in a lower clearance rate of the therapy drugs from the body. These values are based on a patient 1.7 m in height and weighing 70 kg. GFR test results must be normalised to this height and weight (details of this normalisation are given later in this report). A patient's GFR may be affected by a number of factors including pregnancy, kidney disease and blood glucose control in patients with diabetes.

The test

A nuclear medicine test may be carried out to evaluate the GFR of a patient.

The GFR test at this hospital consists of intravenous administration of ⁵¹Cr labelled ethylenediaminetetraacetic acid (EDTA) via a venflon. This is accompanied by pre- and post- injection flushes with saline. The pre-injection flush is carried out to ensure that the venflon is correctly inserted and that no tissue of the radioisotope will occur. The post-injection flush is to flush the residual isotope out of the venflon so that as much as the activity as possible is delivered to the patient. The maximum activity used for a GFR test is 3 MBq for adults and is scaled according to weight for patients under 18 years old.

A blood sample is then taken 2 hours post-injection and 4 more at 45-minute intervals thereafter. A reference and standard dose are created for each batch of ⁵¹Cr labelled EDTA and are used to produce a ratio to link the counts from the twin crystal to the well counter counts. The twin crystal counter is an activity counter comprising two NaI crystals, each coupled to a PMT. Selection of energy thresholds and windows for each crystal allows the counter to measure the activities of two isotopes simultaneously. If an isotope, other than the isotope of interest, is present and emits photons at a higher energy, these photons can undergo Compton scattering. In this process the photons lose energy. If their energy is within the threshold of acceptance

for the isotope of interest when these photons are incident on the NaI crystal they can cause erroneous counts for that isotope. The use of dual threshold measurement with the twin crystal counter allows correction of the isotope of interest's count for contamination by these additional isotopes.

The use of a reference and standard gives a method of calculating what the count for the dose in the well counter would have been at administration under the same conditions. This is to enable the counts from the samples taken later to be expressed as percentages of administered dose/ml. The reference and standard are each similar in activity and volume to the doses as a 2 ml activity in a syringe. However, while the reference is kept for the duration of the batch in its original form, the standard is diluted to 250 ml with water. 4 ml is drawn up and counted with the samples. The reference to standard ratio is measured upon their creation. Measurement of the reference in the double crystal, followed division by the reference/standard ratio, yields the count that would have been obtained by measurement of the original standard in the twin crystal counter at that time. Measurement of the dose then allows the user to find the standard/dose ratio. When the 4 ml aliquot of standard is measured in the well counter, the counts for the total standard can be calculated by dividing by 4 and multiplying by 250 (i.e. total volume of standard). Having obtained the total standard count, dividing by the standard to dose ratio gives the well counter count for the total administered dose. The sample counts divided by this calculated count and the volume of the samples will give the samples counts as a percentage of the dose per ml.

The GFR test and its calculations are based on compartmental analysis, in which the intra- and extravascular spaces are considered to be two connected compartments. The compartment configuration is given in fig. 3.2.1 below.

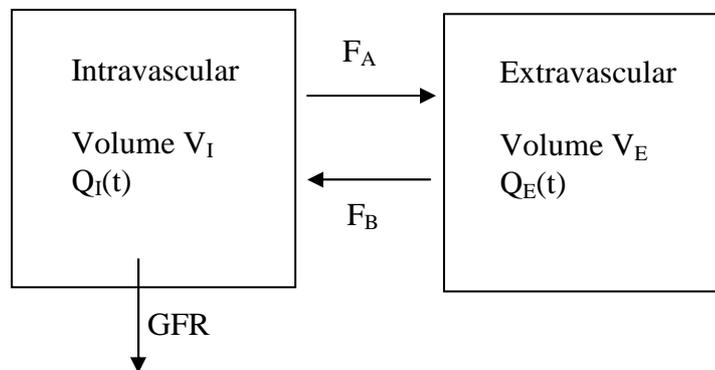


Figure 3.2.1

The following assumptions about this model are made:

- Administration of tracer is into intravascular space as an instantaneous bolus injection.
- Bolus is immediately uniformly mixed within the intravascular space.
- $F_A = F_B$ (F is flow rate).
- Tracer entering extravascular space from intravascular space is due to diffusion gradient and is immediately uniformly mixed.

The rate of change of tracer quantity within the intravascular space $dQ_I(t)/dt$ comprises two components. These are defined by the diffusion of tracer into the extravascular space and by the glomerular filtration.

The following equation (eqn 3.2.1) shows how these components affect the intravascular tracer concentration (C_I).

$$\text{Eqn 3.2.1}^{[11]} \quad \ln C_I(t) = \ln A_1 + \alpha_1 t + \ln A_2 + \alpha_2 t$$

Where:

A_1 = effective initial concentration for diffusion component

α_1 = effective transfer rate for diffusion component

A_2 and α_2 are the same components for the glomerular filtration component.

The concentrations of the intra- and extravascular spaces reach equilibrium and diffusion components become negligible with time. After this point the rate of change of concentration is solely due to glomerular filtration (see Brochner-Mortensen Correction below for expansion on this point).

The practice at this hospital is to allow 2 hours between injection and the first sample for this to occur. Therefore by measuring the tracer concentration of samples (via well counter and use of dose/standard ratio) after the equilibrium point for the majority of patients and plotting $\ln C_I(t)$ versus time a plot of the GFR component is obtained, in which:

$$\text{slope} = \alpha_2 = \frac{GFR}{V_{eff}}$$

and

$$\text{intercept} = \ln A_2 = \ln \left(\frac{\text{Injected dose (well counts)}}{V_{eff}} \right)$$

Therefore:
$$GFR = \text{Slope} * \frac{\text{injected dose (well counts)}}{e^{(\text{intercept})}}$$

This method is known as the “slope-intercept” method for calculating GFR. The calculated GFR is then normalised to that for a “standard man”, assumed to have a body surface area (BSA) of 1.73, by calculation of the patient’s body surface area by the Haycock formula given in equation 3.2.2. This has changed recently from the equation by DuBois and DuBois ^[12].

$$\text{Eqn 3.2.2}^{[13]} \quad BSA(m^2) = 0.024265 * W^{0.5378} * H^{0.3964}$$

Where: S = body surface area (cm^2)
 W = weight (kg)
 H = height (cm)

Therefore normalised patient GFR from slope-intercept method is given by equation 3.2.3.

Eqn 3.2.3

$$GFR_{corr} = GFR_{observed} * BSA / 1.73$$

As ^{51}Cr has a half-life of 28 days no correction for decay of samples is necessary.

Brochner-Mortensen Correction

Until recently, no correction was made for the fast exponential component. The equation therefore became a simple single-exponential equation. However, the guidelines produced by Fleming *et al* ^[12] in August 2004 show that the calculation of GFR by ignoring the fast exponential component in the above method leads to an overestimation of the GFR. The GFR is more accurately given by considering area under the dual-exponential curve. As the analysis of a single-exponential curve is considerably easier than that of a dual-exponential curve, the guidelines suggest correcting the observed “slope-intercept” GFR by normalising to a BSA of 1.73m² and applying quadratic equation 3.2.4. This is the Brochner-Mortensen (BM) correction.

Eqn 3.2.4

$$GFR_{BM,corr} = 1.0004 * GFR_{corr} - 0.00146(GFR_{SI,1.73})^2$$

The guidelines also give the expected GFRs for “standard man” patients aged 20 – 50 and 50 – 75 years as following equations 3.2.5 and 3.2.6:

Eqn 3.2.5: 20 – 50 years

$$GFR = 116 - 0.35a$$

Eqn 3.2.6: 50 – 75 years

$$GFR = 148 - a$$

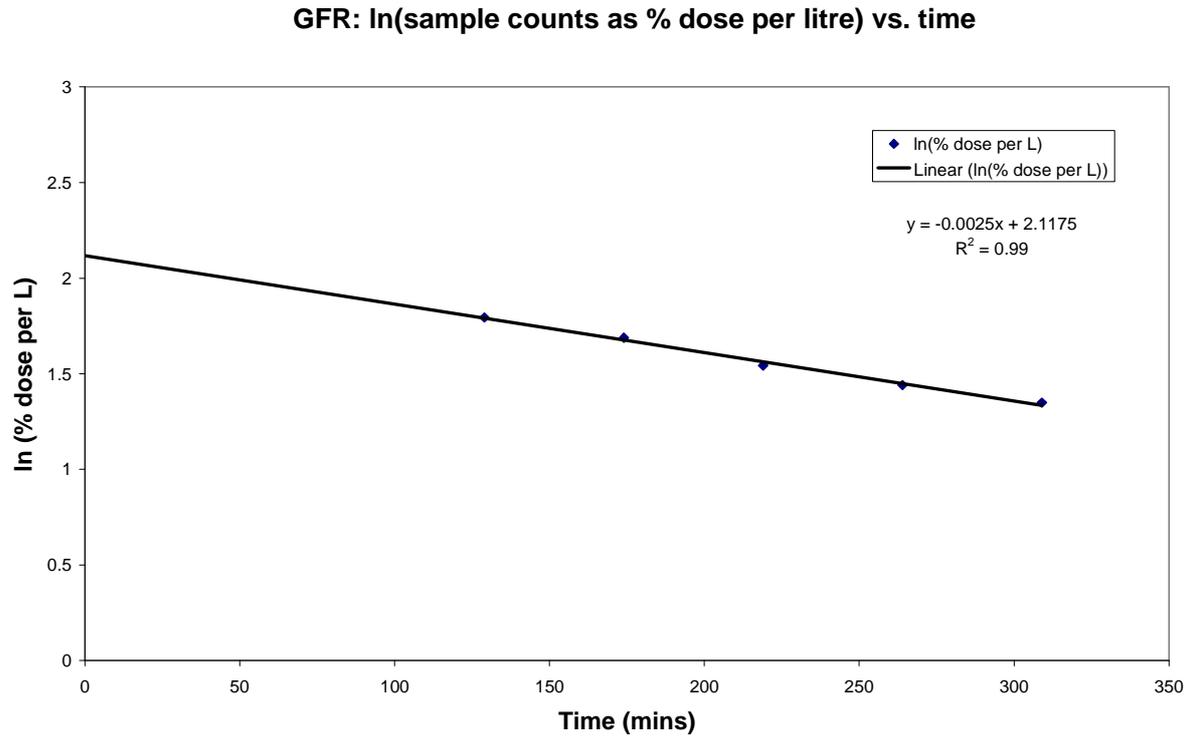
Where: a is the age of the patient in years.

The absolute value of the GFR is then given applying the BSA correction in reverse.

A sample calculation of a GFR and a graph of the points have been included in Fig 3.2.2 and Fig 3.2.3.

Fig. 3.2.2 Sample GFR calculation

Fig 3.2.3 GFR Plot



4. Radiopharmacy

The radiopharmacy supplies the ^{99m}Tc used by the department. It also carries out the preparation of all radio-labelled pharmaceuticals, whether labelled with ^{99m}Tc or other externally supplied isotopes, used in the department. Quality control tests must be carried out to ensure that radiopharmaceuticals produced by the radiopharmacy are of a quality suitable for administration to patients. The general working of the radiopharmacy and the quality control tests performed are discussed below.

4.1 Radiopharmacy observation

Dispensing sessions are carried out by two members of the radiopharmacy staff. They are termed Operator 1 and Operator 2. Operator 1 works within the aseptic suite, making up the doses. Operator 2 works outside the aseptic suite, receiving the doses from Operator 1 through a two-door hatch and recording the relevant information on the injection box labels.

Operator 1 calculates the total activity of radio-labelled pharmaceutical required for a particular type of imaging for the day, prior to entering the aseptic suite. An elution of the Tc-generator is made. The elution vial is measured in the calibrator and the activity per millilitre is calculated. The required total activities can then be drawn up by volume and added to the pharmaceutical kits for each type of scan. These are allowed to incubate for a period of time, again dependent on the pharmaceutical in question. MAG3 for kidneys scans is placed in a heated water bath to assist labelling efficiency. Once incubated the radio-labelled pharmaceutical is drawn up into syringes for each scan. The syringe is measured in the calibrator, which decay corrects the activity to the planned time of administration. Saline is used to make the dose up to the correct volume. The dose is adjusted, if required, until the activity falls within 90 – 100 % of the local dose reference level (LDRL), (see section 7.1), for the scan.

The syringe is kept in a lead pot apart from during manipulation (i.e. drawing up of dose and transfer between the pot and the calibrator), when it is unshielded. Care is therefore taken to minimise the duration of these manipulations. Once Operator 1 is satisfied that the dose is correct for the scan, it is placed into the hatch in the lead pot. The type and time of the administration are called out to Operator 2 along with the activity at the time of measurement. Operator 2 then collects the syringe from the lead pot, placing it into a syringe shield. It is placed into an injection box and the corresponding label attached. The measured activity and time of measurement are recorded on the injection box label and in the radiopharmacy's own records. The syringe boxes are transported by trolley to the Imaging section in the morning before imaging commences. The transport route is planned so as not to cross the main concourse of the hospital or pass the canteen on level five. This minimises any exposure to the public and reduces the number of persons that might walk through any spills, spreading contamination, should they occur.

Whilst it was planned that I should carry out a preparation of an active dose in the Radiopharmacy during my placement, this was not possible due to the radiopharmacy's policy on preparation of doses by trainees. I was, however able to draw up a "cold" stannous dose in the radiopharmacy under aseptic conditions, under the supervision of a radiopharmacist.

4.2 Eluate QC tests

Generator Function

The generator consists of ^{99}Mo (Molybdenum) absorbed onto an alumina column as $^{99}\text{MoO}_4^{2-}$. ^{99}Mo decays by β^- decay to form $^{99\text{m}}\text{Tc}$ (87%) or ^{99}Tc (12.5%). $^{99\text{m}}\text{Tc}$ has a half-life of 6 hours and decays by isomeric transition to ^{99}Tc (half-life 2×10^5 years). The $^{99\text{m}}\text{Tc}$ in the generator forms $^{99\text{m}}\text{TcO}_4^-$ (pertechnetate). During elution of the generator, NaCl is drawn through the generator over the alumina column. The $^{99\text{m}}\text{TcO}_4^-$ is replaced with Cl^- , giving a solution of sodium pertechnetate $\text{Na}^{99\text{m}}\text{TcO}_4$, known as the eluate.

Two other major events that may also occur during an elution are ^{99}Mo breakthrough and Al^{3+} breakthrough. Both of these affect image quality and patient dose. Therefore it is necessary for quality control tests to be carried out on the eluate.

^{99}Mo Breakthrough - Radionuclidic Purity

It is possible to have $^{99}\text{MoO}_4^{2-}$ exchanging with two Cl^- ions in during elution of the generator. The main effect of this is that the $^{99}\text{MoO}_4^{2-}$ will be chemically different to $^{99\text{m}}\text{TcO}_4^-$. A pharmaceutical labelled using $^{99}\text{MoO}_4^{2-}$ may therefore have different uptake and retention characteristics to one labelled using $^{99\text{m}}\text{TcO}_4^-$. The end result would be a distribution of radionuclides in the patient in locations that are not of diagnostic interest and therefore not constructively contributing to the study. ^{99}Mo emits β^- particles (E_{max} 1.214 MeV) and gamma rays at 778 keV, 740 keV and 181 keV [14]. The β^- particles will not contribute to the image and will only serve to increase the effective dose to the patient. On the other hand, the gamma rays may undergo Compton scattering, losing energy. If the gamma rays lose enough energy so as to be within the energy acceptance limits of the gamma camera for $^{99\text{m}}\text{Tc}$ when they reach the detector, then these photons will be seen by the camera as a $^{99\text{m}}\text{Tc}$ gamma ray and registered as a count. These counts will serve to raise background count rate or may induce false radiopharmaceutical foci. A higher Mo content may result from damage to the alumina column (e.g. if the generator is dropped).

^{99}Mo breakthrough tests are carried out for the first elution of a generator and after any movement of the generator. The test involves placing the eluate, in its vial, into the calibrator in a 6 mm thick lead pot. The activity arising from $^{99\text{m}}\text{Tc}$ in the eluate is attenuated by a factor of 10^{-6} . Any activity measured can be assumed to be from ^{99}Mo impurities as these higher energy photons are more. The measured activity must be multiplied by a calibration factor (obtained from the manufacturer of the lead pot) to give the true ^{99}Mo activity. This is because the gamma rays from the ^{99}Mo will be partially attenuated. The activity of the eluate is then measured without the lead pot using the $^{99\text{m}}\text{Tc}$ settings of the calibrator and the Mo/Tc ratio is calculated. The upper Mo/Tc limit is $0.15 \mu\text{Ci}/\text{mCi}$ [15]. As $^{99\text{m}}\text{Tc}$ has a shorter half-life than ^{99}Mo , the calibrator calculates the time at which this limit will be exceeded, alerting the user if that time is less than 12 hours after the measurement.

Al^{3+} Breakthrough – Chemical Purity

Al^{3+} breakthrough occurs when an Al^{3+} ion is exchanged with three Na^+ ions during an elution. This leads to the presence of $\text{Al}(\text{}^{99\text{m}}\text{TcO}_4)_3$ in the eluate. When the eluate is mixed with the pharmaceutical during labelling, the $^{99\text{m}}\text{TcO}_4^-$ in $\text{Al}(\text{}^{99\text{m}}\text{TcO}_4)_3$ may not bind to the pharmaceutical. When the radiopharmaceutical is administered to the

patient the $\text{Al}({}^{99\text{m}}\text{TcO}_4)_3$ will not follow the same distribution pattern as the pharmaceutical, leading to an increased background count, reduced signal to noise ratio and therefore poorer image quality. The patient dose will therefore not be optimised. Additionally competition between Al^{3+} and TcO_4^- for binding sites in the target tissue can lead to the production of free TcO_2^- . High levels of Al^{3+} are also associated with alumina column damage following dropping of the generator.

There are two types of test that can be performed to assess Al^{3+} breakthrough in an eluate. Both tests are based on the fact that Al^{3+} is a 3+ ion and its presence in a solution affects the pH of a solution.

The first test is the one used at this hospital and is carried out twice per week, including on the first elution of the generator. The test uses Al^{3+} indicator papers and a standard Al^{3+} solution of $10\mu\text{g}/\text{ml}$. A drop of the standard solution is placed on one indicator paper and a drop of the eluate is placed on another. The intensities of the colours of the two indicator papers from the two sources are then compared. If the intensity of the colour from the eluate is less than that from the standard solution then the eluate is deemed to have a sufficiently low Al^{3+} content and is fit for use.

The second test may be performed on any elution and involves the use of narrow pH papers and standard pH buffers. The pH buffers correspond to the upper and lower pH allowable pH limits for the eluate. The eluate and standard pH buffers are dropped onto the pH papers and compared. If the pH indicated by the eluate is within the two pH limits then the eluate passes the test. This test is not performed at this hospital.

The first test is more accurate, however the necessity of the standard solution makes this test more expensive to perform than the second test hence the limitation of its use.

4.3 Radiochemical purity test

For each new batch of cold-pharmaceutical (i.e. non-radioactive component of the tracer on to which the isotope is labelled) received by the radiopharmacy, tests are carried out on a labelled sample in order to evaluate the efficiency with which the pharmaceutical binds to the isotope. A batch with a low labelling efficiency would leave unbound ($^{99m}\text{TcO}_4^-$) or free ^{99m}Tc circulating in the body. These unbound isotope species would not accumulate in the same mechanisms as the desired tracer and could increase background noise (reducing image quality) or possibly cause the presence of false foci of uptake in images and thus increase patient dose in these areas unnecessarily.

The test method uses one or two strips of chromatography paper (depending on the pharmaceutical itself) and solvents again dependent on the pharmaceutical to be tested. The first method is used for pharmaceuticals that only leave unbound $^{99m}\text{TcO}_4^-$ only. The second method is an extension of the first method. It is used for pharmaceuticals that can also produce reduced ^{99m}Tc . In this second method, the first part of the test tests for reduced ^{99m}Tc & unbound $^{99m}\text{TcO}_4^-$, and the second part tests for reduced ^{99m}Tc alone.

First let us consider the purity test of MAA, which only tests for unbound $^{99m}\text{TcO}_4^-$. This test utilises one strip of chromatography paper and saline as a solvent. The chromatography paper is cut into a strip 15 mm x 65 mm and marked as shown in fig. 4.2.1. Using a syringe a small quantity of activity is drawn up from the labelled MAA kit used in morning's radiopharmacy dispensing session. A drop of activity is placed at the origin on the strip and allowed to be absorbed. The paper is placed origin first in a vial of the solvent, ensuring the solvent does not cover the origin, and removed when the solvent absorbed reaches the line marked "SF" (Solvent Front). The paper is removed from the solvent vial and cut along the cut line. Both sections are placed in sample tubes and counted in the well counter. Unbound $^{99m}\text{TcO}_4^-$ will be carried with the solvent and relocated to a higher section of the chromatography strip than bound $^{99m}\text{TcO}_4^-$ on the principle of particle size versus speed. Therefore the counts from the origin and solvent front sections of the strip should be due to properly and improperly bound isotope respectively. The labelling efficiency is then calculated as the percentage of total counts originating from the origin section of the paper. Values from an observed test of MAA are shown in an example calculation below.

$$A = \text{Solvent Front Counts} = 225$$

$$B = \text{Origin Counts} = 143621$$

$$C = \text{Total Counts} = A + B = 143846$$

$$\text{Efficiency} = (B / C) * 100 = 99.8\%$$

The second type of test includes an additional strip of chromatography paper, marked as shown in fig. 4.2.2, to that used in the first type of test. Again a drop of activity is placed at the origin of the paper, which is then placed into a solvent vial until the solvent is absorbed up to the SF line. Again the pharmaceutical determines which solvent is used. The test used for labelling efficiency testing of radiolabelled methylene diphosphonate (MDP, used in bone imaging) uses saline and butanone as

solvents to test for unbound $^{99m}\text{TcO}_4^-$ and ^{99m}Tc respectively. The second part of the test is used to detect free and reduced ^{99m}Tc .

In this case the labelled MDP is left at the origin whilst the unbound $^{99m}\text{TcO}_4^-$ is drawn up the chromatography strip in the first part of the test. In the second part of the test unbound and reduced ^{99m}Tc is not carried up the strip by the butanone solvent and so remains at the origin.

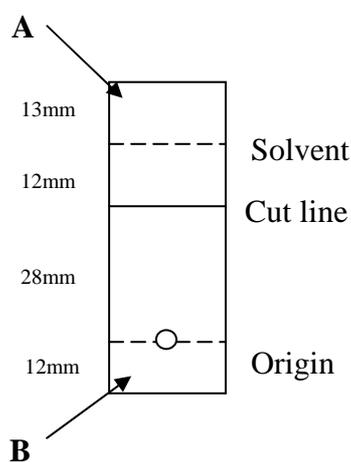


Fig 4.2.1 Test 1 strip mark

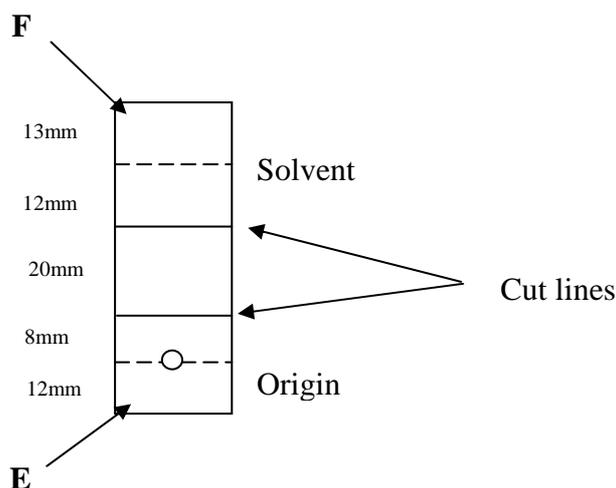


Fig 4.2.2 Test 2 strip mark

The percentage of measured activity from the strip in test 1 due to free $^{99m}\text{TcO}_4^-$ is given by:

$$\% \text{ free } \text{TcO}_4^- = \frac{A}{C} * 100$$

Where:

A = Solvent front counts

C = Total strip counts

The percentage of measured activity from the strip in test 2 due to unbound, reduced ^{99m}Tc is given by:

$$\% \text{ unbound reduced Tc} = \frac{E}{G} * 100$$

Where:

E = Origin Counts

G = Total Counts from Origin (E) and Solvent Front (F)

The labelling efficiency is then calculated as:

$$\text{Efficiency} = 100 - \left(\left(\frac{A}{C} + \frac{E}{G} \right) * 100 \right)$$

The labelling efficiency should be $\geq 90\%$ to be acceptable. Note the middle section in the 2-cut method is discarded.

5. Therapies

The Nuclear Medicine department carries out a range of targeted radionuclide therapies. These utilise the localisation of labelled pharmaceuticals to deliver a dose of ionising radiation (in the form of charged particle emissions) to particular target tissues. Described below are two of the therapies carried out by the department.

5.1 ^{131}I -MIBG Therapy

An ^{131}I -MIBG therapy was carried out on an elderly male patient in the Radio-iodine Therapy suite of this hospital. The treatment comprised an administration of 5.441 GBq ^{131}I labelled metaiodobenzylguanidine (MIBG) to a patient using an infusion pump.

Prior to the patient arriving, the Radio-iodine Therapy suite was prepared by covering the tabletop surfaces and the immediate area around the toilet with Benchcote. This material has an absorbent topside and waterproof underside. This measure was taken to minimise contamination hazards. As MIBG may be excreted in the patient's urine, there is a significant risk of contamination of the floor. The patient was therefore asked to sit when emptying the bladder. If any spills were made in this area the Benchcote would absorb it and could be easily removed, thus preventing long-term contamination of the floor.

MIBG is taken up by catecholamine storage vesicles in adrenergic nerve endings^[16]. This uptake pattern means that MIBG localises in tissues similar to those found in the adrenal glands and can therefore be used to target extra-adrenal tumours consisting of this type of tissue, including pheochromocytoma and neuroblastomas. The mechanism of this uptake arises from the similarity of its chemical structure to noradrenaline and utilises the re-uptake mechanism of noradrenaline by catecholamine storage vesicles. MIBG may be used in both therapy and imaging of these tumours, however imaging uses ^{123}I as the radioactive label instead of the ^{131}I label used in therapy. ^{123}I is solely a 160 keV gamma ray emitter while ^{131}I emits β -particles as well as 360 keV gamma rays. The inclusion of β -particles in ^{131}I emissions makes it less suitable as a diagnostic radionuclide than ^{123}I . The β -particles result in increased effective dose without contributing to the image.

The characteristics that make ^{131}I undesirable as an imaging tracer label make it useful as a therapy label. The aim in MIBG therapy is to deliver a high effective dose to the target tissue. In this instance the β -particles are used to damage and destroy the cells of the tumour. Unfortunately the high-energy gamma rays that accompany β -particle emission have no therapeutic value and result in the patient being an external radiation hazard to those around them. If the radiopharmaceutical used in MIBG therapy was a pure beta-emitter, then while the patient would be a radioactive source, that radiation would be absorbed by the body and not extend far beyond the patient themselves, if at all. However, the gamma emissions may be used to image the patient post-therapy.

The half-life of ^{131}I is 8.1 days. The activity of the radiopharmaceutical remains relatively high for a significant period of time. It was therefore necessary for the

patient to be confined to the Radio-iodine Therapy suite, which is defined as a controlled area, until such a time as their activity was low enough to allow them to be legally discharged. This level is achieved when the activity of the patient is less than 800 MBq.

Assessment of the patient's activity was carried out by first calculating the activity received by the patient at time of administration. That activity was then correlated with the dose measured in $\mu\text{Sv/h}$ on two dose rate monitors, resulting in a calibration factor, which allowed an estimation of retained activity. This process was necessary, as the activity of the patient could not be measured directly. The administered activity was calculated by decay correction of the initial dose activity measurement and back correction of the residue activity to the time of injection. The calculation of the administered activity is shown below. The dose monitors were positioned at waist height at 2 m from the patient.

Initial activity of dose was calculated by taking the mean of two separate, decay corrected, activity measurements of the dose prior to administration. The dose was administered at 4 p.m. on 17/02/04.

1. Activity of dose measured at 10.14 a.m. 17/02/04 = 5.61 GBq

Let this time be $t = 0$.

Administration taken to be at time of first measurement with monitors,
i.e. at 4 p.m. 17/02/04

$\Rightarrow t = 5$ hours 46 minutes.

$$\lambda = \ln 2 / T_{1/2}$$

$$T_{1/2} = 8.1 \text{ days}$$

$$A_0 = 5.61 \text{ GBq}$$

$$A(t) = A_0 e^{-\lambda t} = 5.49 \text{ GBq}$$

2. Activity of dose measured at 12.03 p.m. 17/02/04 = 5.57 GBq

Let this time be $t = 0$.

Administration taken to be at time of first measurement with monitors,
i.e. at 4 p.m. 17/2/04

$\Rightarrow t = 3$ hours 57 minutes.

$$\lambda = \ln 2 / T_{1/2}$$

$$T_{1/2} = 8.1 \text{ days}$$

$$A_0 = 5.57 \text{ GBq}$$

$$A(t) = A_0 e^{-\lambda t} = 5.49 \text{ GBq}$$

The initial activity was therefore taken to be 5.49 GBq at the time of administration. The total residue activity of the needles, delivery tubing, dose containers, gauze and venflon was measured in the calibrator at 2.23 p.m. on 18/02/04 and was found to be 42.33 MBq.

Assuming $t = 0$ at 4 p.m. 17/02/04, it follows that $t = 22$ hours 23 mins at time of residue measurement and A_0 is the residue activity at time of administration.

$$A_0 = \frac{A(t)}{e^{-\lambda t}} = 45.9 \text{ MBq}$$

The net activity administered was therefore 5.4441 GBq.

The mean dose rate measurement taken by the monitors at 4 p.m. 17/02/04 was 82 $\mu\text{Sv/h}$. As the effective dose of a particular type of radiation is proportional to the flux of that radiation, and therefore to the activity of the source, the reading of the dose monitors was directly proportional to the net activity administered. The calibration factor for the monitors in terms of activity was therefore 66.4 MBq/($\mu\text{Sv/h}$). The limit of 800 MBq for discharge would correspond to a monitor reading of 12 $\mu\text{Sv/h}$.

Decay correction could not be used to determine the time at which the patient's activity would be less than the 800 MBq limit to be discharged as this only accounts for the physical half-life of the isotope and not the biological half-life of the radiopharmaceutical. Measurements made of the patient's activity at 24, 46 and 70 hours were used to estimate the effective half-life of the isotope within the patient and therefore the approximate time of discharge.

The measurement at 46 hours gave a dose rate of 20.6 $\mu\text{Sv/h}$, approximately $\frac{1}{4}$ of the initial reading. The effective half-life was therefore considered to be approximately 24 hours. It was unclear as to whether the patient's activity would be below the 800 MBq limit 24 hours later, therefore it was decided to perform a whole body ^{131}I scan on the patient the following day to verify the true activity.

The patient was taken to the imaging section of the Nuclear Medicine department and a whole body scan performed on the Axis gamma camera. An ROI was drawn around the patient on the acquired image with an additional ROI taken over a section of background. The number of counts per second within the patient ROI was background subtracted and a calibration factor applied to give the activity of the patient. The scan method of activity measurement within the patient was thought to be more accurate than the dose monitor method the camera is more sensitive and covers the entire body in the course of the scan. In this case the scan showed a patient activity of 615 MBq. The patient activity was also checked with the dose rate monitors. The final monitor readings obtained were 11.0 $\mu\text{Sv/h}$ & 12.2 $\mu\text{Sv/h}$. This suggested final activities of 784 MBq and 810 MBq according to the monitors. Taking the mean of these three measurements gave a patient activity of 736 MBq. The patient was therefore discharged. While the monitors confirmed the patient's activity to be sufficiently low as to allow discharging there was found to be a discrepancy between the activities calculated by the monitors and the gamma camera methods. If this discrepancy had been large the department would have been obliged to keep the patient in.

It was thought that the discrepancy between the two techniques might be due to geometry differences between the source used to calibrate camera and the sources measured within patients. The ^{131}I calibration of the Axis was previously carried out using a source of known activity in a syringe, placed in a neck phantom. The calibration was designed for use with thyroid measurement and the calibration factor has been adopted for whole body measurements. It was decided to perform a different calibration on the camera to check the validity of this method. See section 6.1 " ^{131}I sensitivity calibration of Axis system", for details.

5.2 Yttrium-90 Therapy

Yttrium-90 (^{90}Y) is used to achieve the reduction of synovial function in articular joints in the treatment of certain arthritic conditions as an alternative to invasive surgical procedures. This method of synovium removal is termed radio-synovectomy. ^{90}Y is produced by neutron bombardment of ^{89}Y in a nuclear reactor and is exclusively a β -particle emitter with a $T_{1/2}$ of 64.4 hours and maximum particle energy of 2.3 MeV. The high Linear Energy Transfer (LET, the energy deposited in a medium per unit distance travelled) and low range of β -particles makes them ideal for this treatment. The range of an ^{90}Y β -particle in soft tissue is approximately 11.1 mm. The localisation in the joint itself and short range mean a low dose to tissues outside of the target area. While the high LET provides damage to the tissues within that range (i.e. the excess synovium).

The therapy uses a dose with an activity of 185 MBq in 2 ml at time of injection and is administered intra-articularly. The original source vial is referenced to a particular date at a particular time stated on the lead container. Decay correction is used to calculate the activity required to be drawn up in the radiopharmacy and to calculate the activity/ml of the source used at this time. This information along with the original source volume will allow the radiopharmacist to determine the volume of source required to be drawn up to yield the correct activity at time of injection. The activity of the dose was also measured in a calibrator prior to administration to check that it was correct.

The administration I observed was carried out by a physician in the company of a nuclear medicine technician and a physicist. A local anaesthetic was applied topically to the joint at the start of the therapy administration. Excess fluid was drawn from the joint using a syringe and a dose of antibiotics administered. A needle was inserted into the joint and a three-way tap attached to it. The ^{90}Y -therapy syringe was then removed from the injection box (still in the syringe shield) and the therapy dose injected via the three-way tap. The syringe was returned to the syringe box and the administration time noted on the box label. Finally a dose of lidocaine and kenalog (anaesthetic & steroid) was administered via the three-way tap. This has three effects. Firstly providing a steroid to the knee to help reduce inflammation in the joint, secondly providing an anaesthetic for the pain that ^{90}Y can induce in the joint and thirdly to flush any residual ^{90}Y from the dead space in the three-way tap and needle into the patient. The pain relief from ^{90}Y takes a couple of weeks to take effect. The steroid is used to provide temporary pain relief until this happens. However, the steroid only provides cover for a couple of weeks, whereas the ^{90}Y pain relief lasts for months once it takes effect. ^{90}Y is of value in patients who have to receive repeated steroid doses for pain relief.

The protection issues in this therapy differ slightly from the standard considerations in the nuclear medicine department. Firstly the isotope used is exclusively a β -particle emitter. This means that the syringe shield and cin-bin & active waste container must be made of Perspex and not lead. Lead is suitable for gamma ray emitters due to the high penetration quality of gamma ray and the need for highly attenuating material. β -particles are readily attenuated, however, being spinning charged particles, they produce x-rays when they are decelerated. This is known as Bremsstrahlung radiation and is due to the interaction of the charged β -particle with the nuclei of the

attenuating material. The cross-section of Bremsstrahlung production is proportional to atomic number of the attenuating material. Therefore, while lead will completely attenuate the β -particles it will produce Bremsstrahlung x-rays. Hence using a greater thickness of a lower atomic number material to shield the syringe and active waste will attenuate β -particles while producing negligible quantities of Bremsstrahlung. Whilst lead will also produce x-rays when used to shield ^{99m}Tc it cannot be substituted with a lower atomic number material because of the highly penetrative nature of the gamma rays emitted. During the administration of the therapy an absorbent sheet was placed under the treated joint to absorb any spills that may occur. The floor area immediately around the patient's bed was monitored for any contamination after the therapy using a Geiger counter. A significant complication is that ^{90}Y therapies are delivered in the Clinical Investigation Unit (CIU). The relatively long half-life ^{90}Y would mean that any contamination would take a significant amount of time to decay naturally. The combination of this with the accessibility of the CIU by staff, patients and visitors makes any contamination a very significant radiation protection hazard needing immediate control measures.

6. The use of ^{131}I in Nuclear Medicine

^{131}I is a commonly used isotope in Nuclear Medicine, both diagnostically and therapeutically. It emits both β -particles and γ -radiation making it a therapeutically useful isotope that can also be imaged by a gamma camera.

6.1 ^{131}I Sensitivity Calibration of the Axis System

Introduction

The gamma camera is sometimes used to measure the activity of ^{131}I taken up by organs or specified volumes within a patient, uptake in the thyroid or whole body of a patient as part of a diagnostic ^{131}I study. These studies may be performed post-operatively or as a follow up study, a long time post-therapy, for thyroid ablation therapies if continued thyroid function is suspected.

Diagnostic ^{131}I scans can be used to assess the presence & extent of ectopic thyroid tissue, as a check for residual thyroid tissue following surgical thyroidectomy and for the detection and assessment of thyroid metastases in the rest of the body from a known primary thyroid tumour. In the case of surgical thyroidectomy, a patient will often be referred for an ^{131}I thyroid scan to assess whether there is a sufficient quantity of residual tissue to require ablation therapy.

Although $^{99\text{m}}\text{TcO}_4$ is the most frequently used radiopharmaceutical for other thyroid scans (due to shorter half-life and absence of β -particles in the emissions of $^{99\text{m}}\text{Tc}$), these studies use 75 – 150 MBq Na^{131}I instead. This is because it better matches the uptake patterns of the therapy dose when treating very small thyroid tissue remnants. It also gives better indication of ectopic thyroid tissues. Some departments allow one month between scan and therapy dose administration to reduce the likelihood of thyroid stunning of the therapy. This is the effect by which the uptake of the therapeutic dose may be reduced by the diagnostic study dose ^[17]. This is not the practice followed at This hospital, as it requires the patient to be kept hypothyroid for the month, which is uncomfortable for the patient.

By measuring the activity in the syringe before and after administration, the delivered activity can be determined. An image is acquired three days post-administration. This delay ensures sufficient time for ^{131}I uptake by the thyroid and its clearance from the rest of the body. Regions of interest can then be drawn around the thyroid and a background region on the image to obtain the background netted counts in the thyroid. If the delivered activity is decay corrected to the time of image acquisition and a conversion factor is applied to the netted counts (counts \rightarrow activity) the percentage uptake of the dose by the thyroid can be determined. At This hospital if the thyroid uptake is less than 0.3% then the patient is not given ^{131}I therapy, but instead is treated with surgery or anti-thyroid drugs (see section 6.2).

Scans may also be performed shortly after administration of a therapy dose. These scans can give diagnostic information with no increase in the dose to the patient. They can be used to check that the therapy dose is taken up into the same regions as the diagnostic scan. The higher activity of the therapy dose, relative to the diagnostic dose, may also allow smaller thyroid tissue remnants to be observed. Additionally the

system may be utilised to measure the residual activity. This is used to revise the restrictions of patients' behaviour and the duration of those restrictions.

This splits the uptake measurements into two different categories, those focusing on the thyroid and those considering uptake throughout the rest of the patient depending on the object of investigation. The latter measurement can be used to determine whether MIBG or ^{131}I ablation therapy patients' activities are sufficiently low as to be under the legal limit to be discharged from the hospital (and controlled area of the Radio-iodine Therapy suite). Although the activity is measured and calculated as described in the MIBG Therapy section of this portfolio (section 5.1), the scan measurement is used as a secondary check to the dose rate meter.

The procedure described in Section 1 below is used to calibrate the gamma camera sensitivity for ^{131}I measurement of the thyroid itself. The calibration factor has been calculated based on a syringe of activity used to represent the thyroid. Currently this calibration factor is applied to whole body ^{131}I scans as well. Discrepancies between activity measurements made using the monitors have led the department to consider that this method may not be entirely accurate. It is thought that the geometry of the distribution of the source in this case may be the cause and a separate calibration factor may need to be determined for whole body measurements using a larger-sized source. It was decided to perform a second calibration with the source in bags to check the results of the syringe calibration method. This is covered in the second section of this report. The calibration uses syringes containing ^{131}I to simulate thyroids of known activities, which can then be imaged and the image analysed to obtain a calibration factor.

Section 1: Thyroid Calibration

Procedure details

A 300 MBq source of ^{131}I was ordered from the manufacturer. An initial concentration of 1 MBq/ml was required. 1 ml of ^{131}I was drawn up from the source vial and its activity measured in the calibrator. The activity was found to be 35 MBq. A dilution of this aliquot in a flask with 34 ml of water would give a source of the desired concentration. Before this dilution was carried out the flask was rinsed with a small quantity of stable sodium iodide (NaI) added to water in order to block any binding sites in the glass.

From the dilution three samples were created by drawing 15, 5 and 1 ml from the flask into three separate 20 ml syringes. The contents of each syringe were made up to 20 ml with additional water.

1 ml of diluted source was drawn up and further diluted with water to 100 ml in a second flask (again the binding sites were blocked prior to dilution). This gave a solution with an activity concentration of 0.01 MBq/ml. Two further sources were created by drawing up 15 and 1.5 ml of this second dilution into two more 20 ml syringes. Again, these were made up to a volume of 20 ml with water. All of the above was carried out behind a lead "castle" wall in a fume cupboard to minimise the dose to the operator and to contain and minimise the risk of contamination. This was carried out over absorbent paper on a drip tray so that if any contamination did occur

it could be more easily dealt with. The area was monitored at the end of the procedure.

This process provided five 20 ml sources with expected activities of 15, 5, 1, 0.15 and 0.015 MBq numbered 1 to 5 respectively. Each syringe was measured in the calibrator three times and the average activity taken. The time and date of measurement was recorded for use in later calculations.

Camera

The camera was set up to acquire an ^{131}I whole body image of a neck phantom (see fig. 6.1.1) over a 70 cm length at 5 cm/min. These parameters were chosen to match those used when imaging patients. The camera head was positioned directly above the phantom at 11 cm from the upper surface. This was chosen as the approximate distance of the detector above the thyroid of a patient during a scan. Images were acquired of the phantom with each of the syringes inserted in turn. The imaging start and stop times were recorded.

Fig 6.1.1 Neck phantom used in syringe ^{131}I calibrations



Analysis

Regions of interest (ROIs) were drawn around the source. A background ROI for each image was also drawn. The number of counts and pixels in each ROI were recorded. The number of counts in each source ROI was background subtracted (scaling background ROI counts up to source ROI area). This provided a netted count for each syringe. The activity of each syringe was decay corrected to the mid-point of the imaging time for that syringe using equation 6.1.1.

Equation 6.1.1

$$A(t) = A_0 e^{-\lambda t}$$

Where:

$$\lambda = \frac{\ln 2}{T_{1/2}}$$

$T_{1/2} = 8.1$ days

A_0 = measured activity

t = time from measurement to image acquisition (days)

This gave a netted count for a known activity for each syringe at the time of imaging. A plot of netted counts versus decay corrected activity (see fig 6.1.3) with a linear fit applied gave a relationship shown in equation 6.1.2.

$$\text{Equation 6.1.2} \quad \text{Activity (MBq)} = \frac{\text{Counts} + 363.67}{17455.75}$$

$$\Rightarrow \text{Activity (Bq)} = 57.29(\text{Counts} + 363.67)$$

This equation is a manipulation of the line equation in chart 6.1.1. in which the intercept is -363.67 and the slope is 17455.75 cts/MBq.

Hence this equation can be used to calculate the activity of the thyroid as ~ 57.29 Bq/Count.

The line had an R^2 value of 1.00 (2.d.p).

Errors

The radionuclide calibrator has an electrometer error of $\pm 2.0\%$ and a system error of $\pm 0.1\%$ ^[18]. Taking the geometric mean of these gives an inherent calibrator uncertainty of $\sim \pm 2.0\%$. However the use of averaging of three measurements per syringe yields an activity uncertainty of $\frac{\delta A}{\sqrt{N}} = \frac{2}{\sqrt{3}} = \pm 1.2\%$ for the measure activities.

Section 2: Whole body calibration

Procedure Details

A syringe of ^{131}I was drawn up from the original source. The activity of the syringe was measured in the calibrator. A few millilitres were then injected into a saline bag (labelled "A") and the syringe activity was measured again. A few more millilitres were then injected into a second saline bag (labelled "B") and the syringe activity measured a third time. Each time the activity was measured the date and time were recorded for the purposes of decay correction. All manipulations of the source and active syringe were carried out behind a lead castle in a fume cupboard over a drip tray, which was lined with absorbent paper. This was to minimise the risk of external dose to the operator and enable any spills to be easily cleared up.

Camera

The bags were imaged individually and then simultaneously on the Axis system using the ^{131}I whole body protocol. The bags were placed on the couch with the camera head directly above the table at a distance of 20 cm from the bag(s). The system was set to image over a length of 70 cm at a rate of 5 cm/min. Imaging start and stop times were recorded for each scan.

Analysis

An ROI was drawn around the source and an area of background for each of the acquired images. The background counts were subtracted from the primary ROI in the same way as for the thyroid calibration above. The activities of the bags were calculated to the mid-point of the relevant scans by applying a decay correction (eqn 6.1.1) to the appropriate syringe measurements, those being:

For Bag A image Measurements 1 and 2
For Bag B image Measurements 2 and 3
For Bag A&B image Measurements 1 and 3

The difference between the decay corrected measurements yields the decay corrected activity of the sources imaged at the time of imaging.

A plot of netted counts versus decay corrected activity gave a linear relationship (see fig 6.1.4). The equation of the line of best fit applied is given in equation 6.1.3, rearranged in terms of activity.

$$\begin{aligned} \text{Equation 6.1.3} \quad \text{Activity(Mbq)} &= \frac{\text{Counts} + 33721}{16934} \\ \Rightarrow \text{Activity(Bq)} &= 59.05 * (\text{Counts} + 33721) \end{aligned}$$

This equation is a manipulation of the line equation in chart 6.1.2. in which the intercept is -33721 and the slope is 16934 cts/MBq.

Hence this equation can be used to calculate the activity of the bags as ~ 59.05 Bq/Count.

This line had an R^2 value of 1.00 (2.d.p).

Errors

The activities of the bags were calculated from the activity measurements of the syringe before and after injecting the bag. As each measurement was made once, the error in the syringe activities are $\pm 2\%$ (inherent uncertainty). The error of the calculated activities of bags A and B (separately) is therefore given by combination of the absolute errors of the syringe activities in MBq (eqn 6.1.4). The activity of bags A and C was calculated by subtraction of the third syringe measurement from the first. The error of the combined activity is still, therefore given by equation 6.1.4.

Eqn 6.1.4

$$\begin{aligned} Z &= A - B \\ \Rightarrow (\Delta Z)^2 &= (\Delta A)^2 + (\Delta B)^2 \end{aligned}$$

Where ΔA and ΔB are the absolute errors in values A and B respectively. The errors are summarised in the table in fig 6.1.2

		Decayed Activities (MBq)	Error (%)	Combined Error (MBq)	Combined Error (%)
Bag A Image	Meas 1	238.3	2.0	6.0	10.1
	Meas 2	179.3	2.0		
Bag B Image	Meas 2	165.2	2.0	3.4	2.7
	Meas 3	37.0	2.0		
Bag A & B Image	Meas 1	178.7	2.0	3.6	2.4
	Meas 3	30.2	2.0		

Fig 6.1.2 Table of errors

Conclusion

Comparison of the calibration factors for syringe and bag imaging methods, (approx. 57.29 and 59.05 Bq/count respectively), shows a slight discrepancy in the sensitivity of the system when using these different source geometries. The current calibration for any ^{131}I activity measurement carried out using the Axis system is 55 Bq/count. These values are sufficiently consistent, considering the increased error in the bag method, to confirm the validity of the current procedure.

Discussion

The count densities of the bag images are greater than those of a post-therapy whole body ^{131}I scan. The count densities of the bag images ranged from 319 to 726 counts/pixel while the count density of a sample whole body scan was found to be 27.6 counts per pixel. The distribution of the activity is also not consistent between the two images. The counts are evenly distributed over the bag image while the whole body image has a focus of higher count density around the thyroid than the rest of the image. The count density of the 15 MBq syringe image was found to have a count density (for the ROI of the syringe) of approximately 403 counts/pixel. The ROI of the thyroid in the clinical image had a count density of 505 counts/pixel. The count densities of these cases are fairly similar.

The images could be made more patient representative of patient images by using a larger phantom. Ideally this would be a fill-able “body” phantom, as it would more closely match the patient geometry of the clinical situation. However, as the department does not have such a phantom one would need to be made up. This would be expensive. Another solution would be to use a flood phantom. This would not be as close a match but would be inexpensive as the department already has a flood phantom. The question then becomes one of cost versus benefit. In either case, a syringe of activity could be included to represent the higher uptake in the thyroid.

Syringe Calibration - Netted ROI Counts vs Activity

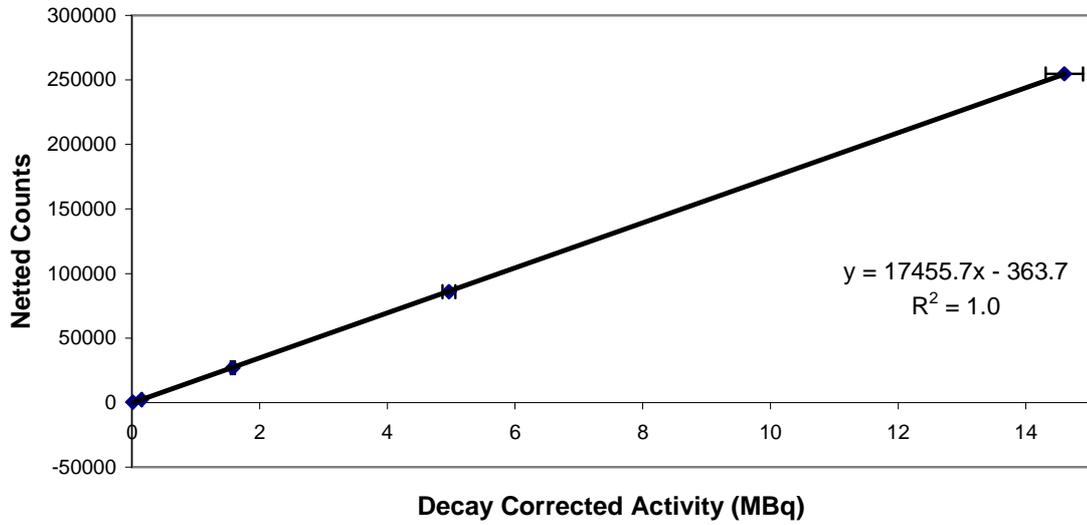


Fig 6.1.3 Syringe Calibration plot

Bag Calibration - Netted Counts versus Activity

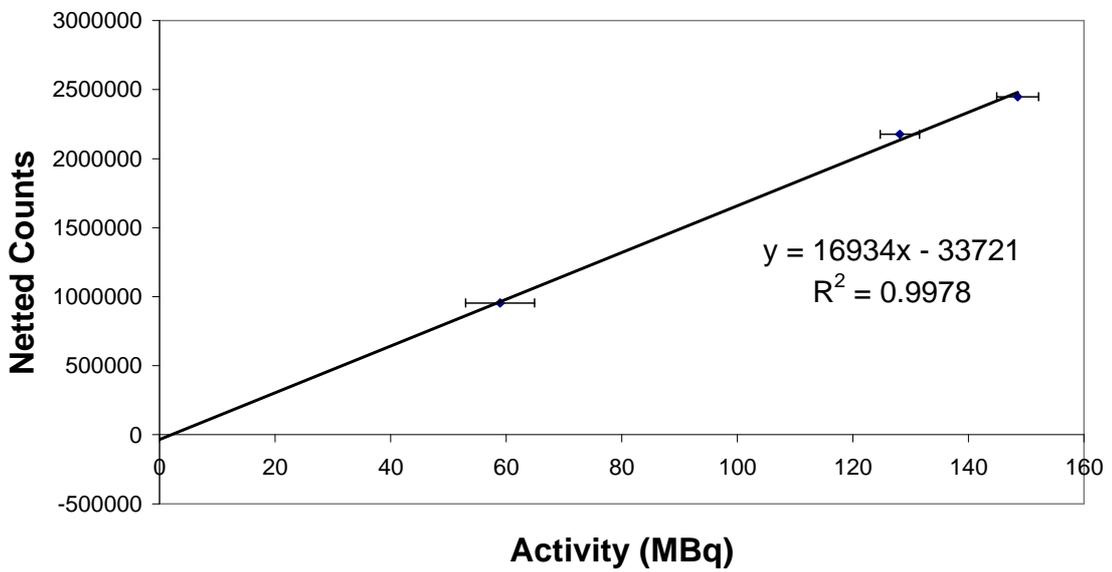


Fig 6.1.4 Bag Calibration plot

6.2 Thyrotoxicosis therapy

Patients with thyrotoxicosis (hyperthyroidism) are divided into three categories. The first are those with Graves' disease, which presents a uniformly overactive thyroid and is often (but not always) accompanied by disease of the eyes causing them to protrude (exophthalmos). In Grave's disease the increased thyroid activity is due to stimulation of the thyroid stimulating hormone receptors by antibodies against them. The other categories are single thyroid nodule (STN) and multi nodular goitre (MNG). These correspond to localised region(s) of overactive thyroid tissue. In thyrotoxic patients Graves' disease is the most common form, accounting for 80 % considering all ages and genders. STN and MNG account for 5 % and 15 % respectively as shown in fig 6.2.1. In older patients the percentages of Graves' and MNG may change to 60 % and 35 % respectively, however the percentage of patients with STN remains fairly constant.

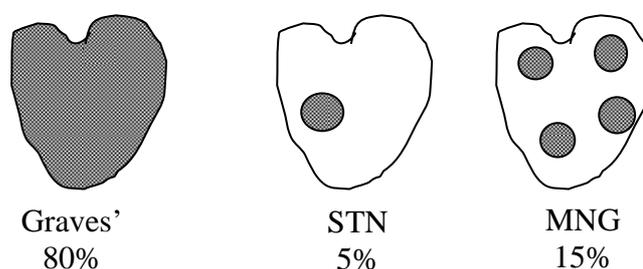


Fig 6.2.1 Typical ^{131}I distribution patterns in thyroids of patients with Graves' disease, STN and MNG. Grey indicates high uptake.

The patient's treatment plan depends upon the cause of their thyrotoxicosis, life-style and domestic issues and an evaluation of likely compliance with restrictions.

^{131}I emits both gamma rays (360 keV) and β -particles ($E_{\text{max}} = 0.61 \text{ MeV}$) whilst ^{123}I emits only gamma rays (160 keV). In diagnosis it is the gamma rays that are useful, allowing the patient's thyroid to be imaged with a gamma camera. In purely diagnostic studies, therefore, ^{123}I is the better labelling isotope to use as it delivers a lower effective dose to the patient than ^{131}I . However, in therapy the dual emission modes of ^{131}I are beneficial as the β -particles induce the required biological damage, while the gamma rays allow the iodine distribution in the thyroid tissue to be imaged. Sodium pertechnetate ($\text{Na}^{99\text{m}}\text{TcO}_4$) is also taken up by the thyroid and is used in some diagnostic studies. Although its uptake does not exactly match that of iodine it gives sufficient uptake distribution information about the thyroid on this scale. $^{99\text{m}}\text{Tc}$ has a shorter half-life than either of the iodine isotopes

A patient presenting with a goitre, positive blood test and evidence of Thyroid eye disease is almost certain to have Grave's disease and will not require further diagnostic investigation with an isotope thyroid scan. In the absence of associated eye disease a thyroid scan may be performed. The distribution of ^{123}I uptake in the thyroid is different for each category (fig 6.2.1). Patients with Graves disease demonstrate uniform high uptake over the entire thyroid, while scans of patients with STN demonstrate single focus of high uptake with a low level of uptake in the rest of the thyroid. MNG patients demonstrate an uneven distribution with multiple foci. In some cases the rest of the thyroid may not be visible on the scan as a negative

feedback mechanism suppresses normal thyroid tissue in the presence of toxic nodules. Iodine isotopes are used in these studies as the thyroid uses iodine in the production of thyroid hormones. ^{123}I uptake is a marker of thyroid physiology.

Most Grave's disease patients will, on first presentation, be treated for 1 year with anti-thyroid drug therapy. Of these patients approximately $\frac{2}{3}$ are cured while $\frac{1}{3}$ relapse. The relapse can occur at any time, but is most common between 6 months and 1 year after the drugs are stopped. For these relapse patients the choices for the next course of treatment are:

1. To be put back on anti-thyroid drugs such as carbimazole to render the patient euthyroid (normal). Cure rate after 1 year is only 4 % with this option. While there are no longer-term side effects there are logistical issues as GPs are unwilling to alter thyroid patient prescription doses. Therefore patient must see a consultant regularly
2. Radio-iodine therapy with ^{131}I .
3. Surgery to remove part or all of thyroid (thyroidectomy).

Some clinicians offer patients ^{131}I therapy as a first line therapy. Patients are initially rendered euthyroid with anti-thyroid drugs. Some patients, particularly those who do not have children at home, do not wish to undergo the relative uncertainty of the 12-15 month course of anti-thyroid medication and opt for ^{131}I therapy. This is a choice that must reflect the individual patient's domestic circumstances and informed consent.

Grave's disease patients having radio-iodine therapy will receive dose activities between 400 and 750 MBq. The upper limit of administered activity is below 800MBq to avoid the patient being kept in Hospital. Whilst the ideal outcome is to render the patient euthyroid, this cannot be reliably achieved with any degree of certainty. This is due to differences in the uptake and rate of excretion from patient to patient. As a consequence, most clinicians choose to err on the side of caution, with post-therapy hypothyroidism perceived as the preferred option when compared to post-therapy hyperthyroidism (i.e. failed treatment).

The treatment of choice for STN patients is ^{131}I therapy, the activity of the therapy being decided by the referring consultant (typically between 400 and 500 MBq). STNs are resistant to anti-thyroid drugs. As iodine uptake is suppressed in the rest of the thyroid in STN, the dose to the nodule may be quite high, removing it, while sparing the healthy tissue. STN treatments are more likely to result in the patient being rendered euthyroid.

In patients with MNG, much depends on whether the patient has symptoms of extrinsic compression of the trachea or oesophagus, in addition to the presence or absence of hyperthyroidism. Patients with extrinsic compression symptoms will usually require surgery. Hyperthyroid patients with large MNG causing extrinsic compression should also be treated with surgery. Hyperthyroid patients with MNG who do not have symptoms of extrinsic compression may be suitable for ^{131}I , if the 20 minutes uptake in a sodium pertechnetate ($\text{Na}^{99\text{m}}\text{TcO}_4$) study is sufficiently high. If neither ^{131}I therapy nor surgery options are suitable then long-term anti-thyroid medication may be required. $\text{Na}^{99\text{m}}\text{TcO}_4$ is used for this uptake measurement rather

than Na^{131}I or Na^{123}I as Iodine studies dictate a 2-day imaging procedure to allow localisation of the Iodine isotope.

^{131}I therapy and surgery both have the same net effect, the destruction of thyroid tissue, and many patients will subsequently develop hypothyroidism and be put on thyroxin long-term to compensate. The deciding factors between radio-iodine therapy and surgery from a patient point of view are life style & domestic arrangements of the patient and reluctance of the patient concerning radiation. Female patients may have young children. This could make limiting contact with children difficult. Some patients are concerned about the affect of ^{131}I therapy on fertility. At this hospital all patients receiving radio-iodine therapy are advised not to conceive children until 6 months after the treatment.

During my placement in Nuclear Medicine I observed several thyrotoxicosis therapy sessions and administered a therapy myself under supervision. The therapy involves the administration of ^{131}I in a capsule. The patient is first asked to state their name, address and date of birth as a patient identity check. The therapy administrator then talks to the patient about the safety measures to be taken, which are laid out in the information leaflet given to the patient before attending. Any question or concerns that the patient may have are discussed. The patient is then told that the capsule will be placed in a steret vial in a lead pot. They are instructed to then lift the vial to their lips, tip the capsule into their mouth and swallow without chewing. A cup of water is provided to help with this. The patient is then issued with a card and asked to keep it on their person for a period of time dependent on the activity of the therapy dose. The purpose of this card is to inform hospital staff that this person has undergone a thyrotoxicosis therapy if they should be taken to hospital and are unable to inform anyone themselves.

^{131}I is taken up by the active thyroid tissue to be used in the production of thyroid hormones. The therapy utilises the emission of β -particles by ^{131}I . These cause damage to cells within their effective range, from their interactions with cells. The mean particle range of β -particles emitted by ^{131}I is 0.8 mm ^[19].

The measures discussed include how long to remain off work, how long to limit prolonged contact with others, how long to avoid contact with young children and pregnant women, and the necessity to make separate sleeping arrangements for those who usually share a bed with another person. These measures are required, as the patient becomes an external radiation source upon swallowing the therapy capsule. These limitations exist to reduce the dose to other persons. As these persons do not benefit from the dose, unlike the patient, their dose must be kept as low as reasonable achievable.

The dose received from an external source obeys the inverse square law (when considering point sources), doubling the distance between source and the exposed individual reduces the dose to a quarter. Close contact is defined as being within 1 m one person. Similarly, patients are asked to sleep separately from others, preferably in separate rooms but at least in separate beds 2 m apart.

The limits imposed depend on the activity of the dose received by the patient. A patient receiving a 500 MBq therapy would be asked to limit close contact with

others, over 5 years old, to 30 minutes per day for 13 days. This limit is increased to 18 days for 3 to 5 year olds and 23 days for children less than 3 years old.

Patients are also asked to keep a separate set of cutlery and crockery to use for 3 days following the therapy. These are to be washed separately from, and after others. The reason for this is that during this period ^{131}I , free in the body, will be excreted in the patient's urine, sweat and saliva. The patient therefore presents a contamination risk during this period. In addition to separate cutlery and crockery, the patient is asked to wash their hands thoroughly whenever preparing food and to flush twice when visiting the toilet.

The aim of the above restrictions is to keep the doses to others not receiving the treatment below their dose constraints and limits. These limits do not necessarily apply to all who may be exposed to by a radioactive patient equally.

In fact there are three groups of people that can be considered separately in these circumstances. The first group includes the general public, being anyone that is not an occupationally exposed radiation worker and not living with the patient. The second group includes other members of the patient's household, and the third group includes comforters and carers. Comforters and carers are defined in Ionising Radiations Regulations 1999 as being individuals that are not occupationally exposed radiation workers who "knowingly and willingly incur an exposure" whilst supporting and caring for a patient receiving a medical exposure^[20].

The dose constraints for these groups from a single patient treatment are 0.3 mSv, 1 mSv and 5 mSv respectively. In addition to these dose constraints, the first two groups also have dose limits of 5 mSv in any 5-year period^[21]. This dose limit does not apply to comforters and carers.

Whilst this is acceptable under the legislation, it is not the practice carried out at this hospital. The view of the Nuclear Medicine department is that patients may arrive for treatment without any or all of their comforters and carers being present. Informed consent of the comforters and carers would therefore rely on the full communication of the details to these persons by the patient (and/or others present at the time). This added level of complexity introduces uncertainty in the level of information received by these persons. The department therefore adopts the principle of treating those living with or caring for the patient as members of the public having a dose constraint of 1mSv per patient exposure and a dose limit of 5 mSv in 5 years.

The department at This hospital previously used liquid ^{131}I , which the patients were asked to drink. However, this represented a high contamination risk if patient or administrator spilt the liquid. A dropped capsule may be quickly returned to a lead pot, negating the exposure, while a liquid spill takes considerably longer to clear up.

Patients have follow up appointments with their consultant approximately 6 weeks after administration of the therapy.

Thyroid Ablation Therapy

For thyrotoxicosis therapy patients, the aim of the therapy is to reduce the activity of an overactive thyroid. Thyroid ablation is a more extreme form of this therapy. Thyroid remnant ablation therapy is used in conjunction with surgery (thyroidectomy) in the treatment of patients with Differential Thyroid Cancer (DTC). DTC includes the papillary and follicular variants of thyroid cancer. DTC cells behave like normal thyroid cells in that they often can be shown to take up iodine. This is used to provide imaging evidence of metastatic disease or recurrent disease, and as a prelude to therapy.

Patients with DTC undergo total or sub-total thyroidectomy, often with the removal of the lymph nodes adjacent to the thyroid. Patients are then referred for a diagnostic whole body ^{131}I scan. This can be performed either 2-3 weeks post operatively or, if the patient is started on Thyroxine or T_3 supplements, at a date several months later.

DTC cells are stimulated to divide by high thyroid stimulating hormone (TSH) levels. As a consequence, the diagnostic scan is performed when the patient is deliberately rendered hypothyroid (i.e. with a high TSH level). This increases the sensitivity of the test. Patients are administered 150 MBq of ^{131}I as a diagnostic dose, and return 3 days later for imaging. At that time an ROI is drawn around the thyroid bed. A decision as to whether to treat with ^{131}I ablation therapy is made on the basis of a number of patient specific factors as to whether Thyroid Remnant Ablation is required. These factors include the histological type of the tumour, the size of the lesion, the presence or absence of lymphatic or vascular spread, the age of the patient and the findings on the diagnostic scan.

In cases where Thyroid Remnant Ablation is required, the patient will then receive an ablation therapy dose of ^{131}I , again in capsule form. The activity of the dose is decided by the Nuclear Medicine Consultant but is typically of the order of 3 GBq. As in the case of MIBG therapy patients (section 5.1), the patient is kept in the Radio-iodine Therapy suite and monitored until their activity falls below 800 MBq, when they may be legally discharged. Again, as for MIBG therapy patients, the Axis camera system is used on the final day to measure and confirm the patient's activity (see ^{131}I sensitivity calibration of the Axis system, section 6.1). The aim of ablation therapy is to destroy all residual thyroid tissue. Post-therapy scans can in theory demonstrate lesions not visible on the lower activity diagnostic scan.

7. Projects

Detailed in this section are three projects carried out during my placement in the Nuclear Medicine Department.

7.1 Audit of Paediatric Administered Activities

An audit was conducted of administered doses for all paediatric imaging studies performed over the three-month period from October to December 2003.

The department has scaling factors, taken from the Administration of Radioactive Substances Advisory Committee (ARSAC), which are used to scale the Local Diagnostic Reference Levels (LDRL) for particular investigations, according to weight, to doses that are acceptable for use with children. These scaled LDRLs are referred to as Paediatric Local Diagnostic Reference Levels (PLDRLs). They are applied to children and young persons aged less than 18 years and are based on weight. Children weighing more than 70 kg receive 100 % of the adult LDRL.

Policy within the department has been to use doses between 80 and 100 % of the calculated PLDRL for any one paediatric patient.

An audit conducted between October and December 2002 found that, out of 59 patients in that period, six received doses that fell outside of the 80 – 100 % acceptability range.

The audit was repeated to investigate the effectiveness of actions suggested by the previous audit.

Background

Each type of scan in the department has a prescribed activity for the radiopharmaceutical involved. The doses are ordered from the radiopharmacy, where they are drawn up each morning before the imaging schedule starts. If the activity is not within 90 – 100 % of the DRL for the scan, the volume of drawn tracer is adjusted and re-measured until the activity is within these limits. While doses within 90 – 100 % limits are acceptable, a range of 95 – 100 % is more desirable especially for scans that are to be performed later in the afternoon. This is because delays to the start time of these scans are common due to accumulated delays throughout the rest of the day. If the dose is intended for a paediatric study the DRL for the study, and therefore the drawn dose, are scaled according to the patient's weight by the ARSAC scale. The dose is then made up to the standard volume with saline. The dose is passed out of the aseptic suite through a hatch to the second operator who notes the current activity and time of measurement on a record sheet and the label of the relevant injection box. Operator 2 also performs periodic checks of doses intended for adult studies using a second calibrator. This check should be carried out for all doses intended for paediatric patients. The dose is placed in a lead-lined injection box labelled with the appropriate patient details and radiopharmacy information and delivered to the imaging section.

Immediately before the administration of radiopharmaceutical the dose's activity is measured in the Imaging section's dose-calibrator to check that the dose is within 80 – 100 % of the DRL for the study. The patient (or guardian if the patient is too young) is asked to state their name, date of birth and address, which are checked against the patient's request form and injection box label. Female patients between the ages of 12 – 55 are also asked to state the date of their last period and whether they might be pregnant. The dose is then administered according to the test procedure and the time of injection is recorded on the injection box. The syringe is re-measured in the calibrator to obtain a residue measurement, which is recorded with the measured activity against the relevant study on the radio-isotope laboratory copy of the day's study list. The residue is subtracted from the activity measurement made immediately prior to injection and this residue corrected activity is recorded on the injection label and the patient's request form. The injection box label is removed from the box and attached to a sheet of paper with other labels and filed. These labels are retained for a period of a few months so as to be available in case of necessity for referral (e.g. in audit).

Results

A summary of the results of this audit is given in Table 1.

Dose Audit
Oct 2003 - Dec 2003

Paediatric Studies	Dy Kidneys	Static Kidneys	Bones	Total
No. Carried out	16	27	3	46
Av. %age of PLDRL	92	89.3	94.9	90.6
Std Dev.	3.37	4.83	2.72	4.53
Max	97.5	99.3	96.9	99.3
Min	85	81.6	91.8	81.6
>100% of PLDRL	0	0	0	0
<80 % of PLDRL	0	0	0	0
<90 % of PLDRL	4	16	0	20
%age between 80 - 100 %	100	100	100	100
%age between 90 - 100 %	75.0	40.7	100.0	56.5

Table 1 Summary of Audit results

As can be seen from this data, no studies had administered doses greater than 100% or less than 80 % of the PLDRL.

A total of 20 studies carried out fell outside the 90 % limit. These included 4 dynamic kidney scans and 16 static kidney scans.

Inspection of the injection box labels and decay correction of the activities thereon to the intended and actual injection times revealed that, in theory, activities would have fallen within the 90% limit if they had been injected at their intended times for 11 of the studies. One study's injection box label did not contain activity and time information from the radiopharmacy department. This data was obtained from the radiopharmacy department's documentation.

A second study's injection box label did not contain the actual injection time. This information could not be found anywhere else. As logging the time of administration

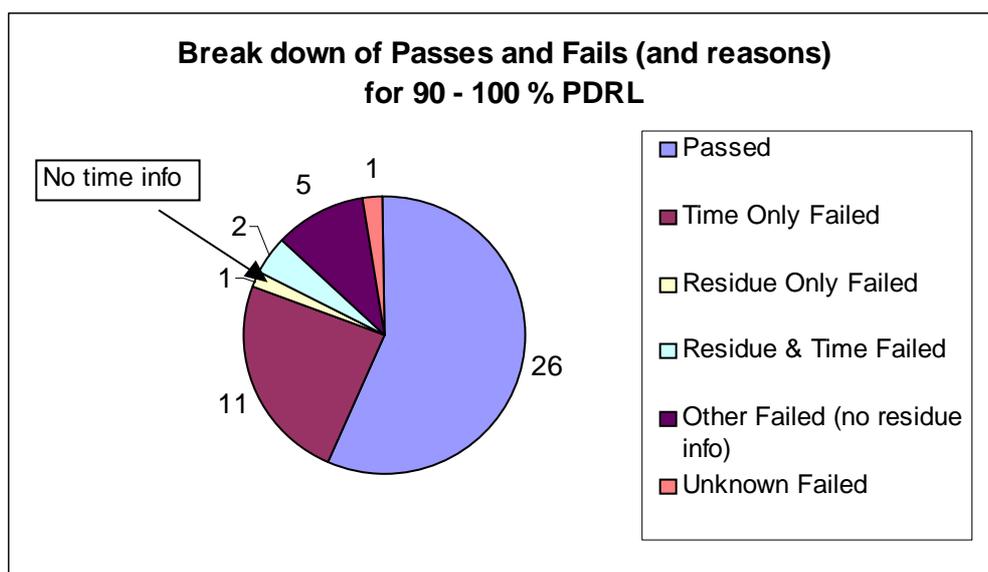
of a dose is an important part of administration procedures this presents an error and it cannot be known whether administration was delayed and if so by how much. Without this information an activity decay correction cannot be made to the time of injection.

It was found by decay correction of the activities from the predicted injection times to the actual injection times that 11 of the studies fell outside of the 90 % limit. It was also found that the activities of 8 of the studies should have fallen within the 90% limit. These failures are possibly due to a combination of delayed injection time and residue in the syringe.

Of the 8 non-time failure cases, residue counts could only be found for 3 cases. Of these 3 cases it was found that residue activity in the syringe accounted for the administered activity falling short of the 90 % limit in 2 cases. The cause of the shortfall in the third case is unknown and extent of the effect of the syringe residue activity cannot be estimated in the remaining 5 cases.

In summary, of 46 scans:

- 46 within 80 – 100 % of PDRL
- 26 within 90 – 100 % of PDRL
- 20 fell short of 90 % limit
 - 11 due to delayed injection time
 - 2 due to syringe residue and delayed injection time
 - 1 not explained by combination of syringe residue and injection time alone
 - 5 with no residue activity information
 - 1 with no injection time information but would have passed if residue activity was added
- 0 exceeding 100% limit
- 1 case radiopharmacy information not present on injection box label, though this information found in radiopharmacy documents.



Discussion

While there are a number of gaps in the information recorded (i.e. the missing residue activities and injection time) it is recognised that new referral forms have been implemented in the department since the period covered by this audit. These forms are structured in such a way as to group all required measurements and recorded data together. This should make missing information more obvious at the time of completion of the form and thus reduce the occurrence of omission of such data in future. The largest contributor to doses falling without the 90-100% limits is delayed injection times. These delays are often incurred due to difficulties with inserting venflons into paediatric patients. These procedures are carried out by staff in the paediatric ward and are beyond the control of the Nuclear Medicine department. As the activity of the radiolabelled pharmaceutical is calculated to the planned administration time, delays in administration cause the administered activity to be lower than planned due to radioactive decay.

It should be noted, however, that the doses considered in this audit meet the limits suggested by ARSAC and any failures are only with respect to the department's own, more stringent, limits.

Actions to be taken

No action is required, but it is recommended that senior staff discuss the possible alteration of the time between insertion of the venflon and planned administration time. Increasing the time allowed between these events may help to buffer any unexpected delays.

7.2 NPL Calibration

The Nuclear Medicine department's dose calibrators are calibrated annually against the National Physical Laboratory (NPL) primary standard to ensure that the activity measurements made by them are accurate. Calibrations are carried out for each of the isotopes used by the department on a rotation. ^{99m}Tc is calibrated for each year along with a selection of other, less often used, isotopes. During my placement in Nuclear Medicine I was asked to organise and carry out an NPL calibration as a project. This involved liaising with NPL, a licensed radioactive materials carrier, the Radiation Physics department of This hospital, the radiopharmacy and the Nuclear Medicine laboratory section staff.

The calibration took place over the course of 3 days. It involved measuring the isotopes concerned in the department's calibrators and then sending them to NPL to be measured. The two sets of measurements were compared and adjustments made as required.

The outline of the process is as follows:

- Day 1: Isotopes (other than ^{99m}Tc) arrive and are measured in calibrators.
- Day 2: ^{99m}Tc supplied by radiopharmacy and is measured in calibrators. All isotopes are packaged up and up-lifted by carrier.
- Day 3: Isotopes delivered to NPL by 12 noon and activity measured.

NPL results are provided with times and dates of measurements within a few weeks.

It was decided to use ^{99m}Tc , ^{67}Ga , ^{90}Y and ^{131}I for the calibration.

NPL request activities of more than 50 MBq referenced to midday on the day of delivery, if possible, (the lowest activity accepted is 10 MBq), for measurement in their calibrator. The radiopharmaceutical companies that provide the isotopes not supplied by the radiopharmacy (i.e. not ^{99m}Tc) have set activities they can supply. The combination of these two factors lead to the decision of what activities were to be used in the calibration. This decision was made after consultation with the senior technician of the laboratory section.

Quotes were obtained from the radiopharmaceutical companies (through the lab section technician) to supply the three non-Tc isotopes, for the carrier to deliver the isotopes from this hospital to NPL, and for NPL to perform the calibration. These quotes were given to the head of department for approval. A start date of the calibration was decided on through discussion with the parties involved that was suitable. This depended on the availability of NPL staff on the third day to carry out the calibrator measurements, carrier availability to carry out up-lift and delivery, isotope availability and This hospital's staff availability.

In this particular case the ^{90}Y could only be delivered on alternate Fridays, the carrier could not up-lift on a Wednesday and carry out delivery the next day and NPL could not have the delivery day on a Friday. This, factored with staff availability, required

that Day 1 start on Monday 31st May 2004. Once the date was agreed by all parties and the quotes approved, the details were confirmed with the appropriate persons. 580 MBq of ^{99m}Tc was ordered from the radiopharmacy for Day 2 at 8:30 a.m.

On Day 1 the isotopes were unpacked and the packaging kept for later use. The isotopes were measured in each of the department's calibrators three times with the correct settings selected. A second set of measurements was made for each isotope using the "other" button and the appropriate dial-in factor. The date and time of each measurement was recorded. Aseptic procedures were followed when working in the blood labelling suite and aseptic suite in the radiopharmacy. The isotopes were stored to be re-packaged using the original packaging on Day 2.

On day 2 the ^{99m}Tc source was collected from the radiopharmacy and measured in each of the calibrators. The isotopes were packaged. A spare set of packaging had been kept from a previous delivery.

As the original packaging was used to re-package the non-Tc isotopes, it was acceptable if they exceeded the limits for excepted packages and could be sent out as type-A packages. This is due to the fact that the packaging they were delivered in must have been sufficient for its classification. This was not true for the ^{99m}Tc sample. As this was supplied "in-house", the packaging was made up in This hospital from previous delivery packages. This hospital does not have the necessary QA program in place to allow anything other than excepted packages to be made up on site. Therefore the source had to meet the criteria for an excepted package (Radioactive Substances (Road Transport) Regulations 2002). These criteria dictated a maximum activity of 400 MBq at the time of up-lift.

The packaging procedures provided by the Radiation Physics department were followed and a member of radiation physics staff supervised the process. The surface dose rate and dose rate at 1 m were measured using the Smart Ion monitor. The dose rate at 1 m in mSv was multiplied by 100 to give the transport index (TI) of each package in accordance with Radioactive Substances (Road Transport) Regulations 2002. Surface contamination monitoring was carried out on the packages. The surface dose rate and activity at time of up-lift were used to determine the classification of each package. The ¹³¹I and ⁹⁰Y were sent as type-A packages, while the ⁶⁷Ga and ^{99m}Tc were sent as excepted packages.

Each package was labelled as appropriate under the regulations, with isotope, chemical form, activity, TI, date, package type & classification, and surface dose rate where required. Consignor notes were prepared, filled in and then signed by the supervising physicist and the carrier.

A spreadsheet was prepared for each calibrator containing the measured activities of each isotope under each setting along with date and time. The averages of each of set of three measurements were taken and referenced to the mid-point time of the three measurements. The NPL measured activities and times of measurement for each isotope were entered into the spreadsheet. Each of the averaged local measurements was decay corrected to the times of the NPL measurements and the percentage differences calculated. Factors were also calculated to correct local measured activities to those measured at NPL. These are given in the tables in fig 7.2.1.

Machine	Tc Button % diff	Factor
HLL 15R	-2.97	1.0297
HLL 120	-2.79	1.0279
IDG	-5.69	1.0569
Imaging	-2.63	1.0263
Blood Lab	-2.66	1.0266
Aseptic	-1.56	1.0156

Machine	Tc Dial-in % diff	Factor
HLL 15R		
HLL 120	-2.9670	1.0297
IDG		
Imaging	-2.7886	1.0279
Blood Lab		
Aseptic		

Machine	Ga-67 Button % diff	Factor
HLL 15R	-0.33	1.0033
HLL 120	2.46	0.9754
IDG	-0.91	1.0091
Imaging		
Blood Lab	-0.23	1.0023
Aseptic	-0.76	1.0076

Machine	Ga-67 Dial in % diff	Factor
HLL 15R		
HLL 120	1.9653	0.9803
IDG		
Imaging	0.4379	0.9956
Blood Lab		
Aseptic		

Fig 7.2.1. Summary tables of percentage differences and correction factors for ^{99m}Tc and ^{67}Ga for each calibrator. (Blank spaces mean this option was not applicable).

Once the correction factors were calculated new calibration factors could be found. For this, a radioactive source was placed into the calibrator. The activity measured was multiplied by the correction factor to acquire the true activity. Different calibration factors were tried on the calibrator until the true activity was achieved.

For example, the activity measured with the High Level Laboratory (HLL) 15R calibrator was 72.5 MBq when using the Tc button (calibration factor 81). The true activity was therefore given by $72.4 \times 1.0297 = 74.6$ MBq. Using a calibration factor of 76 with the source in place gave an activity of 74.6 MBq. The Tc button was therefore reprogrammed to use a calibration factor of 76. This was carried out for each isotope on each machine. Where dial-in factors were used the dial-in factor was changed on the list on the calibrator.

Note: HLL is High Level Laboratory
IDG refers to the ImmunoDiagnostic Group

7.3 Risk Assessment for Staff performing unsealed radioisotope manipulations within the Nuclear Medicine Imaging Section

I was asked to draw up a radiation risk assessment as required by *Management of Health and Safety at Work Regulations 1992, regulation 3, paragraph 3(b)* referred to in *IRR99, regulation 7, paragraph 4*. What follows is the full text of the risk assessment.

Reason for risk assessment

To determine whether adequate controls are in place for the manipulation of unsealed radioisotopes by staff in the nuclear medicine imaging. To ensure compliance with dose limits and constraints for staff involved, and areas used. This risk assessment considers only doses arising during, or as a direct result of, manual handling of unsealed radioisotopes performed in nuclear medicine imaging section (e.g. not including exposure from patient during course of a scan).

Procedures involved

Creation/loading of phantoms by scientific staff in QC tests.

Adjustment of doses by technical staff prior to injection.

Administration of doses by technical staff (incl. calibrator measurement of doses).

Handling of unsealed sources in other QC tests (daily floods, centre of rotation & calibrator linearity testing).

For ease this report will be separated in 3 sections: Patient Administrations, Phantoms and Other QC.

1. Patient Administrations

Area

Camera Rooms P7 163, P7 164 & P7 168; Administration Room P7 157b;
Radioisotope Lab P7 170 and Bed & Chair Waiting Area of Nuclear Medicine Imaging OP5A.

Description of Work

Scanned patients are administered a dose of a drug labelled with a radioisotope, often by injecting. Doses are contained within a syringe, supplied in a syringe shield in a lead shielded injection box. The syringe activity is measured in the isotope laboratory's dose calibrator (for this the syringe is briefly unshielded). The dose is then taken to the camera room or injecting room to be injected into the patient by a technician (exception of tetrofosmin stress studies, where the dose is administered by the consultant clinician in the bed waiting area). The syringe shield remains in place during administration. The most common high dose scan is the bone scan, which uses 600 MBq ^{99m}Tc -MDP.

Sources of radiation

$^{99m}\text{Technetium}$, which emits 140 keV gamma radiation.

Half-life 6.02 hr

Hazards (Radiation Accident)

Hazards may arise from injection of small volumes of ^{99m}Tc . Extremity and external whole body exposures occur during handling of the syringe during injection and measurement in dose calibrator.

Staff involved

Nuclear medicine technical imaging staff (8 technicians) and medical staff.

Doses

The total doses per year associated with each group of persons involved in administration of dose are as follows.

Clinicians: External Whole Body = $0.411 \mu\text{Sv}$
Extremity = 6.49 mSv

Technicians: External Whole Body = $6.54 \mu\text{Sv}$
Extremity = 103.38 mSv

Details of the determination of these doses are given in the dose calculations section of the appendix. Technician doses given are per technician average over 9 technicians. Clinician doses given are per clinician averaged over 2 clinicians.

2. Phantoms

Area

Gamma camera rooms P7 163, P7 164 & P7 168 and Radioisotope Laboratory P7 170

Description of Work

SPECT, Shell & Contrast phantoms and line source phantom use ^{99m}Tc sources made up from a ^{99}Mo generator in the Aseptic suite of the radiopharmacy.

SPECT (Jaszczak) phantom is loaded with activity in the Radioisotope laboratory and mixed. It is then taken through to the camera room, the test set up and left to run over night. The room is closed and entry prohibited until the next day. Phantom is moved back to the radioisotope lab the next morning and placed behind the lead wall to decay.

Shell & Contrast phantoms are loaded in the radioisotope laboratory from the same, shielded, source syringe. Half is loaded into each of the phantoms, which are then mixed and taken through to the camera room.

Line source phantom consists of 5 parallel glass tubes, which are loaded from a shielded syringe in the radioisotope laboratory. The phantom is then taken into the camera room for the test. The test procedure involves lifting and moving the phantom several times.

^{131}I calibration tests are in two forms. Firstly, 5 syringes of varying activities, made up in the laboratory section, with an average activity of 5 MBq. During the test the syringes are, in turn, removed from the trolley, inserted into the neck phantom, imaged and then returned to the trolley. Direct contact is with the 5 unshielded syringes lasting for 2 minutes in total. The second method uses two saline bags loaded with ^{131}I . This is a new calibration method without a formal written procedure as yet,

which may or may not be permanently adopted. Therefore the risk assessment is based on the quantities and structure of the experiment as performed. The bags contained 50 and 250 MBq of ^{131}I . They were made up in the laboratory and delivered to the axis gamma camera room in a shielded trolley. They were removed and imaged individual and then jointly. The total handling time was approximately 1 minute.

Sources of radiation

$^{99\text{m}}\text{Tc}$ Technetium, which emits 140 keV gamma radiation.

Half-life 6.02 hr

^{131}I Iodine, which emits 360 keV gamma radiation and β -particles with $E_{\text{max}} = 0.61$ MeV.

Half-life 8.01 days

Hazards (Radiation Accident)

Hazards may arise from loading phantoms and manual handling while performing tests.

Staff involved

Nuclear medicine scientific staff. (Currently 1 physicist carries out all phantom QC tests described here).

Dose Assessment

The physicist's annual doses from manipulating unsealed sources in the tests outlined above are:

External Whole Body = 11.4 μSv
Extremity = 8.79 mSv

Details of the determination of these doses are given in the phantom dose calculation section of the appendix.

3. Other QC

Area

Camera Rooms P7 163, P7 164 & P7 168; Radioisotope Lab P7 of Nuclear Medicine Imaging OP5A.

Description of Work

Daily floods – Three sources of $^{99\text{m}}\text{Tc}$ are made up in the radiopharmacy each day and are used as provided. The sources are in syringes and arrive in injection boxes. The camera detectors are set-up, without the collimators in place and the each source placed along the mid-line of the detectors at a distance of $5 \times \text{FFOV}$. At the end of the tests the syringes are returned to the injection boxes. The syringes are unshielded during positioning and throughout the tests.

Centre of Rotation (CoR) – Three $^{99\text{m}}\text{Tc}$ sources are provided by the radiopharmacy each week. Two are used as provided; the third is used to load the 3-point jig for the Axis system. The first two positioned in the field of view of the detector(s)

unshielded. The tests are performed, after which, the syringes are re-shielded and returned to the injection boxes. The 3-point jig is loaded from the third CoR source in the radioisotope laboratory in the imaging section. Once loaded the jig is carried into the Axis camera room and set-up for the test.

Calibrator linearity – A source of 3 GBq is provided by the radiopharmacy in a P6 vial. It is measured in the dose calibrator approximately 4 times a day for 5 days. Each measurement session consists of 3 individual measurements.

Sources of radiation

^{99m}Tc, which emits 140 keV gamma radiation.

Half-life 6.02 hr

Hazards (Radiation Accident)

Hazards may arise from injection of small volumes of small volumes of ^{99m}Tc in 3-point jig loading for Axis CoR. Extremity and external whole body exposures occur during handling of the syringe during positioning for daily floods and CoR and measurement in dose calibrator for dose calibrator linearity.

Staff involved

Nuclear medicine technical imaging staff and scientific staff.

9 imaging technicians and 1 physicist carry out daily floods.

1 physicist carries out CoRs

Usually a trainee physicist carries out calibrator linearity test. (Person changes each year)

Dose Assessment

The total doses per year associated with each group of persons involved in these QC tests are as follows.

Physicist: External Whole Body = 9.12 μ Sv
Extremity = 12.66 mSv

Technician: External Whole Body = 0.28 μ Sv
Extremity = 4.43 mSv

Details of the determination of these doses are given in the dose calculations section below. Technician doses given are per technician average over 9 technicians.

Exposed Groups and Dose Constraints

The staff considered in this assessment are all radiation (non-classified) workers over the age of 18 years. Dose constraints for radiation (non-classified) workers are; 6 mSv whole body, 150 mSv extremity.

Assessment of Total Annual Staff Doses

The total annual doses for each group for all activities considered above are:

Clinician: Whole Body = 0.411 μ Sv
Extremity = 6.49 mSv

Technician: Whole Body = 6.82 μ Sv
Extremity = 107.81 mSv

Physicist: Whole Body = 20.51 μ Sv
 Extremity = 21.48 mSv

The worst contamination doses of ^{131}I and $^{99\text{m}}\text{Tc}$ from a single incident will be:

$^{99\text{m}}\text{Tc}$ – Loading Axis CoR jig

Whole Body dose = 11.75 μ Sv

Skin dose = 14.76 mSv from 90 MBq deposited on 25 cm² area

^{131}I – Whole body ^{131}I Axis calibration

Whole Body dose = 9.11 μ Sv

Skin dose = 27 mSv from 90 MBq deposited on 25 cm² area.

The staff dose constraint of 50 mSv for a single incident is not exceeded

Control Measures

All staff wear protective gloves & clothing when handling unsealed sources.

Self monitoring is carried out regularly to check for any contamination.

Shielding is used wherever practicable to reduce exposures by attenuation.

Staff minimise their contact time when handling unsealed sources and ensure that sources are handled at a distance from the body.

Only qualified personnel handle unsealed sources.

Conclusion

It is recognised that the external whole body doses given above are a small percentage of the annual staff doses. However, the technician extremity doses calculated in this risk assessment greatly exceed the known extremity doses (from monthly and annual monitoring). These calculated doses are an overestimation of the extremity doses received by technical staff. It mainly arises from the handling of patient doses when measuring in the calibrator. The assumption that all scans are bone scans is a worst possible case scenario and the true average activity will be lower than this. Even under these exaggerated conditions the extremity dose still does not exceed the staff dose limit.

Adequate measures are in place for the manipulation of unsealed sources.

Action to be taken

No further action is required at this point, however, continual assessment is recommended as the workload of the imaging section increases.

8. Legislation

The Nuclear Medicine department is governed by numerous pieces of legislation. In addition to legislation applying to any workplace, such as Health and Safety at Work Act 1974, are five specific pieces that apply due to the use of unsealed radioactive material. There are three important items in the legislation. Firstly there are Acts and Regulations, which are the legal requirements in their original form. These pieces of legislation are written in legal terminology and may be difficult to understand by a layperson. The acts and regulations are interpreted in guidance notes, such as the Medical and Dental Guidance Notes (A good practice guide on all aspects of ionising radiation protection in the clinical environment). The guidance notes are not mandatory but it is good practice to follow them. This will ensure that the requirements of the legislation are met. Finally, the local rules of a department are the implementation of the legislation in the work place locally.

ARSAC certificates

The Administration of Radioactive Substances Advisory Committee (ARSAC) is the committee established to advise health ministers on granting, renewing, revoking and amending authorisation for individuals to administer radioactive medicinal substances to humans. This authorisation is given in the form of an ARSAC certificate. An ARSAC certificate must be held for each type of radionuclide procedure carried out in the Nuclear Medicine department, under the Medicines (Administration of Radioactive Substances) Regulations 1978 (MARS78). The ARSAC certificate holder must be a Practitioner (see IR(ME)R 2000 below) qualified in working with radiation. The certificate must be specific to the current site and the Practitioner must be based on-site to be the certificate holder. The certificate holder is ultimately accountable for authorisation of all procedures carried out under the certificate. This authorisation may be carried out by named, medically qualified, health professionals as long as the pre-arranged authorisation procedures are followed.

Ionising Radiations Regulations 1999 (IRR99)

The presence of sources ionising radiation in the department necessitates its governance by and adherence to the Ionising Radiations Regulations 1999 (IRR99).

IRR99 is in place to protect members of the public (including non-occupationally exposed members of staff) and radiation workers with regards to ionising radiation. It defines constraints on the annual doses received by persons in the department, according to their designation. Members of the public may receive up to 1 mSv per year, whilst radiation workers may receive a maximum of 20 mSv per year. Any radiation worker receiving more than $3/10^{\text{th}}$ of their dose limit in one year must be declared as a classified person.

IRR99 also states the requirement for designation of areas as public, supervised or controlled.

The regulatory body for IRR99 is the Health & Safety Executive.

Ionising Radiations (Medical Exposures) Regulations 2000

In both sections of the Nuclear Medicine department, radioactive pharmaceuticals are administered to patients. They therefore undergo medical exposures, which must be subject to the Ionising Radiations (Medical Exposures) Regulations 2000 (IR(ME)R2000).

IR(ME)R 2000 defines three types of people involved with a medical exposure. These are Practitioners, Operators and Referrers.

In Nuclear Medicine:

Practitioners are registered medical practitioners (Nuclear Medicine consultants). They are the ARSAC certificate holders.

Operators are entitled to carry out practical aspects of a medical exposure.

Referrers are registered medical practitioners and are entitled to refer patients to the practitioner for a medical exposure.

This NHS Trust has a “Policy for the implementation of IR(ME)R2000”, which dictates who may perform which duties (by profession and grade). The Nuclear Medicine department keeps local records of individual staff members authorised to perform these duties.

The objective of IR(ME)R2000 is to protect persons undergoing medical exposures to ionising radiation. This is achieved through two main principles, defined in and required by the regulations. These are Justification and Optimisation. The former requires that a diagnostic procedure should only be carried out using exposure to ionising radiation if the same information cannot be obtained by methods not involving ionising radiation exposures and where the benefits outweigh the detriment posed to the individual by the exposure. The latter requires that the dose resulting from a medical exposure be kept as low as reasonably practicable whilst obtaining the required information or therapeutic effect. This is why the quality assurance system and QC checks are necessary. A camera system with high levels of noise would require higher doses to achieve the same quality of data or a repeat of the study. IRMER also requires that written procedures be created for all tasks carried out.

In Scotland the regulatory body for IR(ME)R2000 is the Scottish Executive’s Health Department.

Local Rules

Radiation employers are required, under IRR99, to have and keep local rules intended to restrict exposure to ionising radiation in controlled and supervised areas and in the event of a radiation accident. They are designed to allow work with ionising radiation to be carried out in the above areas, in accordance with the regulations, while restricting the exposure of individuals other than the patient receiving the exposure. Under IRR99 the local rules identify the radiation protection supervisor and their duties, the rights and conditions of access to controlled and supervised areas by different categories of members of staff and the arrangements for contamination

monitoring of areas and personnel. They also give the arrangements for dealing with any contamination encountered in these cases. The local rules may refer the reader to other sources for more detailed information/instructions on a particular topic, such as an operational procedures manual for working protocols. There must be a periodic review for updating the local rules and it must be ensured that all members of staff working in the department are aware of and understand these rules and any amendments to them. A programme of review of the received doses should also be included in the rules to determine whether they are As Low As Reasonably Practicable (ALARP) and effect any procedural changes necessary as a result of this review.

Radioactive Substances Act 1993 (RSA93)

This act governs the storage of radioactive substances and disposal of radioactive waste by the department. Storage is subject to certificated holding limits. Records must be kept of all radioactive substances coming into and leaving the department. Storage requirements for solid radioactive waste state that containers used to store active waste are labelled with all the isotopes being disposed of in it (with half-life), the start date, end date and activity at the end date. This hospital's Nuclear Medicine department has a certificate, which states the monthly limits of disposal for each radionuclide. Waste from the Nuclear Medicine department at this hospital is disposed of by incineration in Sheffield. A certain quantity of liquid waste may be disposed of via the hospital drainage system. Records must be kept of quantities disposed of by this method including estimates from excretion by patients in hospital toilets. RSA93 is regulated by the Environment Agency in England and Wales and by the Scottish Environment Protection Agency (SEPA) in Scotland.

A key difference between radioactive disposal in this region compared to that in the rest of the UK is in its approach to clinical waste. In this region all clinical waste associated with the use of radionuclides is assumed to be radioactive. In England it is assumed that if ^{99m}Tc is the used, then clinical waste can be allowed to decay and then be disposed of as household waste.

Radioactive Materials (Road Transport) Regulations

On occasion it is necessary for the department to arrange for transport of radioactive materials to other institutions. These materials must be properly packaged, monitored and labelled according to isotope-type and activity. The requirements are covered by the Radioactive Materials (Road Transport) Regulations. An example of their use can be found in section 7.2, in which radioactive sources were dispatched to NPL in Teddington using these regulations.

Medicines Act

As the radionuclide procedures involved the administration of pharmaceuticals, the department is also covered by the requirements of the Medicines Act 1988. The amended Medicines (Administration of Radioactive Substances) Regulations 1978 require the possession of authorising certificates (ARSAC certificates) for each type of procedure involving administration of a radiopharmaceutical as mentioned above.

9. Contamination Incident

During my placement in the Nuclear Medicine Department a contamination incident occurred. Under supervision by a physicist, I carried out the monitoring and clear up of this incident. A copy of the contamination incident report form has been included in the appendix.

The incident occurred in the Axis gamma camera room during a tetrofosmin study. The patient, having already received the radionuclide dose, vomited during the study contaminating the chest binding, bedding, patient gown and the floor. The area was shut off to others to limit the spreading of any contamination. All those present in the room wore gloves and lab coats. The patient's gown was removed and changed and the patient was removed from the room. The patient's gown, chest binding and bedding were monitored with a mini-monitor 900 contamination monitor and their counts recorded. These articles were deposited in polyethene bags and placed behind the lead castle in the radioisotope laboratory, to decay. The floor, couch and camera heads were also monitored. The couch and camera were found to be clear of contamination, while the floor contained a pool of liquid in an extended area immediately around the couch and spots over an area ~ 1 m x 1.5 m. The counts in this area were recorded. The liquid was then covered with absorbent tissue. This was also placed behind the lead castle in polyethene bags. Afterwards the floor was re-monitored and the counts recorded. After declaring the area sufficiently decontaminated House Keeping staff were allowed to mop the floor before the room was returned to normal use.

Appendix

Risk Assessment Dose Calculations

The dose estimates have been calculated from known activities, estimated exposure times and activity-dose conversion factors ^[22].

Administration Doses

Dose Calculations

Assumption: 7000 scans per year and scans are shared equally between 9 imaging technical staff. Tetrofosmin stress scans are treated separately in administration dose calculations as these are delivered by clinicians (1100 scans per year).

Calibrator measurement of doses

All scans assumed to be bone scans
Unshielded syringe containing 600 MBq ^{99m}Tc-MDP
Total exposure and contact time approximately 2 seconds
Exposure distance 1 m

External dose (1 scan) = $2.24 \times 10^{-5} * 600 * (2/3600) = 7.47 \times 10^{-6}$ mSv
External dose (per technician per year) = $7.47 \times 10^{-6} * 7000/9 = 5.81 \times 10^{-3}$ mSv

Extremity dose (1 scan) = $0.354 * 600 * 2/3600 = 0.118$ mSv
Extremity dose (per technician per year) = $0.118 * 7000/9 = 91.78$ mSv

There is no contamination, as cap is not removed.
Not volatile form of compound, therefore no internal radiation hazard.

Administrations (Technicians)

5900 Bone scans
Shielded syringe containing 600 MBq ^{99m}Tc-MDP
Total exposure time of syringe ~ 30seconds
Exposure distance 1 m
Shield circa 99 % attenuation

External dose (1 scan) = $2.24 \times 10^{-5} * 600 * (30/3600) * 0.01 = 1.12 \times 10^{-6}$ mSv
External dose (per technician per year) = $1.12 \times 10^{-6} * 5900/9 = 7.34 \times 10^{-4}$ mSv

Extremity dose (1 scan) = $0.354 * 600 * (30/3600) * 0.01 = 0.0177$ mSv
Extremity dose (per technician per year) = $0.0177 * 5900/9 = 11.60$ mSv

Contamination – external dose

Assuming 10 % release onto bench surface during dispensing, 60 MBq
Small volume, therefore “point source” type spill.
Deep tissue dose rate = 2.61×10^{-4} mSv/h at 30 cm.
Exposure time 30 minutes (i.e. max. duration of scan)

Extremity = $2.61 \times 10^{-4} * 60 * (30/60) = 7.83 \times 10^{-3}$ mSv

Contamination – skin dose

Assume 5 % (30 MBq) release onto 25 cm² area of skin, i.e. 1200 kBq/cm².
 Exposure time 2 minutes
 Skin dose rate 0.246 mSv/h (per kBq/cm²)

$$\text{Skin dose} = 0.246 * 1200 * 2 / 60 = 9.84 \text{ mSv}$$

Administrations (Clinicians)

1100 tetrofosmin stress scans
 2 clinicians share stress administration sessions
 Shielded syringe containing 400 MBq tetrofosmin
 Total exposure time of syringe ~ 30seconds
 Exposure distance 1 m
 Shield circa 99 % attenuation

$$\begin{aligned} \text{External dose (1 scan)} &= 2.24 \times 10^{-5} * 400 * (30/3600) * 0.01 = 7.47 \times 10^{-7} \text{ mSv} \\ \text{External dose (per clinician per year)} &= 7.47 \times 10^{-7} * 1100 / 2 = 4.11 \times 10^{-4} \text{ mSv} \end{aligned}$$

$$\begin{aligned} \text{Extremity dose (1 scan)} &= 0.354 * 400 * (30/3600) * 0.01 = 0.0118 \text{ mSv} \\ \text{Extremity dose (per clinician per year)} &= 0.0177 * 1100 / 2 = 6.49 \text{ mSv} \end{aligned}$$

Contamination – external dose

Assuming 10 % release onto bench surface during dispensing, 40 MBq
 Small volume, therefore “point source” type spill.
 Deep tissue dose rate = 2.61x10⁻⁴ mSv/h at 30 cm.
 Exposure time 30 minutes

$$\text{External whole body} = 2.61 \times 10^{-4} * 40 * (30/60) = 5.22 \times 10^{-3} \text{ mSv}$$

Contamination – skin dose

Assume 5 % (20 MBq) release onto 25 cm² area of skin, i.e. 800 kBq/cm².
 Exposure time 2 minutes
 Skin dose rate 0.246 mSv/h (per kBq/cm²)

$$\text{Skin dose} = 0.246 * 800 * 2 / 60 = 6.56 \text{ mSv}$$

Adjustment of Patient Dose

Carried out in a lead shielded handling box with syringe shield in place.
 Manipulation is carried out over absorbent paper in a drip tray.
 Dose adjustment is rare.
 Assume 1 case per week, bone scan 600 MBq (worst case).
 Total time for adjustment 2 minutes.
 Shielding circa 99 % attenuation.

$$\begin{aligned} \text{External dose (1 session)} &= 2.24 \times 10^{-5} * 600 * 0.01 * (2/60) = 4.48 \times 10^{-6} \text{ mSv} \\ \text{External dose (per technician per year)} &= 4.48 \times 10^{-6} * 50 / 9 = 24.9 \times 10^{-6} \text{ mSv} \end{aligned}$$

$$\begin{aligned} \text{Extremity dose (1 session)} &= 0.354 * 600 * 0.01 * (2/60) = 0.0708 \text{ mSv} \\ \text{Extremity dose (per technician per year)} &= 0.0708 * 50 / 9 = 0.39 \text{ mSv} \end{aligned}$$

Contamination – external dose

10 % release on to surface in box, 60 MBq.
Deep tissue dose rate = 2.61×10^{-4} mSv/h at 30 cm
Exposure time ~ 4 minutes.
Shield circa 99 % attenuation

$$\text{External} = 2.61 \times 10^{-4} * 60 * 0.01 * (4/60) = 10.44 \times 10^{-6} \text{ mSv}$$

Contamination - Skin dose

Assume 5 % (30MBq) release on to 25 cm² area of skin, i.e. 1200 kBq/cm².
Exposure time 2 minutes
Skin dose rate 0.246 mSv/h (per kBq/cm²)

$$\text{Skin dose} = 0.246 * 1200 * 2/60 = 9.84 \text{ mSv}$$

Phantom Doses

Dose calculations

SPECT Phantom

Phantom contains 500 MBq ^{99m}Tc
1 physicist
Direct contact and exposure time = 3 minutes
Exposure distance 1 m
Direct contact with 1 % of phantom (affects extremity only)
Test frequency = 3 cameras, 4 times per year = 12 /yr

$$\text{External dose (1 session)} = 2.24 \times 10^{-5} * 500 * (3/60) = 5.6 \times 10^{-4} \text{ mSv}$$

$$\text{External dose (per year)} = 5.6 \times 10^{-4} * 12 = 6.72 \times 10^{-3} \text{ mSv}$$

$$\text{Extremity dose (1 session)} = 0.354 * 500 * (3/60) * 0.01 = 0.0885 \text{ mSv}$$

$$\text{Extremity dose (per year)} = 0.0885 * 12 = 1.06 \text{ mSv}$$

Shell & Contrast Phantoms

Phantoms contain total of 150 MBq ^{99m}Tc
1 physicist
Total direct contact and exposure time = 5 minutes
Exposure distance 1 m
Direct contact with 5 % of phantoms (affects extremity only)
Test frequency = 3 cameras, 3 times per year = 9/yr

$$\text{External dose (1 session)} = 2.24 \times 10^{-5} * 150 * (5/60) = 2.8 \times 10^{-4} \text{ mSv}$$

$$\text{External dose (per year)} = 2.8 \times 10^{-4} * 9 = 2.52 \times 10^{-3} \text{ mSv}$$

$$\text{Extremity dose (1 session)} = 0.354 * 150 * (5/60) * 0.05 = 0.22125 \text{ mSv}$$

$$\text{Extremity dose (per year)} = 0.22125 * 9 = 1.99 \text{ mSv}$$

Line Source Phantoms

Phantoms contain total of 100 MBq ^{99m}Tc

1 physicist
Total direct contact and exposure time = 5 minutes
Exposure distance 1 m
Direct contact with 5 % of phantoms (affects extremity only)
Test frequency = 3 cameras, 3 times per year = 9/yr

External dose (1 session) = $2.24 \times 10^{-5} * 100 * (5/60) = 1.87 \times 10^{-4}$ mSv
External dose (per year) = $1.87 \times 10^{-4} * 9 = 1.68 \times 10^{-3}$ mSv

Extremity dose (1 session) = $0.354 * 100 * (5/60) * 0.05 = 0.0885$ mSv
Extremity dose (per year) = $0.0885 * 12 = 1.06$ mSv

¹³¹I syringe calibration

5 syringes contain average of 5 MBq ¹³¹I
1 physicist
Total direct contact and exposure time (loading and handling) = 5 minutes
During loading procedure body is shielded by lead castle. Other handling is unshielded. Assume 95% body shielding
Test frequency = 2 per year

External dose (1 session) = $6.36 \times 10^{-5} * 5 * (5/60) * 0.95 = 2.52 \times 10^{-5}$ mSv
External dose (year) = $1.007 \times 10^{-5} * 2 = 5.04 \times 10^{-5}$ mSv

Extremity dose (1 session) = $1.13 * 5 * (5/60) = 0.47$ mSv
Extremity dose (year) = $0.1883 * 2 = 0.94$ mSv

¹³¹I bag calibration

Set up uses combination of bags
Average of 200 MBq per bag handling.
1 physicist
Total direct contact and exposure time = 1 minutes
Unshielded
Assume 50% contact with bag.
Test frequency = 2 per year

External dose (1 session) = $6.36 \times 10^{-5} * 200 * (1/60) = 2.12 \times 10^{-4}$ mSv
External dose (year) = $2.12 \times 10^{-4} * 2 = 4.24 \times 10^{-4}$ mSv

Extremity dose (1 session) = $1.13 * 200 * (1/60) * 0.5 = 1.883$ mSv
Extremity dose (year) = $1.883 * 2 = 3.77$ mSv

Contamination – external dose

^{99m}Tc

Assuming 10 % release onto bench surface during loading of SPECT,
50 MBq
Small volume, therefore “point source” type spill.
Deep tissue dose rate = 2.61×10^{-4} mSv/h at 30 cm.
Exposure time 30 minutes

$$\text{External whole body} = 2.61 \times 10^{-4} * 50 * (30/60) = 6.53 \times 10^{-3} \text{ mSv}$$

¹³¹I

Assuming 10 % release onto bench surface from high dose bag,
25 MBq

Small volume, therefore “point source” type spill.

Deep tissue dose rate = 7.29×10^{-4} mSv/h at 30 cm.

Exposure time 30 minutes

$$\text{External whole body} = 7.29 \times 10^{-4} * 25 * (30/60) = 9.11 \times 10^{-3} \text{ mSv}$$

Contamination – skin dose

^{99m}Tc

Assume 5 % (25 MBq) release onto 25 cm² area of skin, i.e. 1000 kBq/cm².

Exposure time 2 minutes

Skin dose rate 0.246 mSv/h (per kBq/cm²)

$$\text{Skin dose} = 0.246 * 1000 * 2/60 = 8.2 \text{ mSv}$$

¹³¹I

Assume 5 % (12.5 MBq) release onto 25 cm² area of skin, i.e. 500 kBq/cm².

Exposure time 2 minutes

Skin dose rate 1.62 mSv/h (per kBq/cm²)

$$\text{Skin dose} = 1.62 * 500 * 2/60 = 27 \text{ mSv}$$

Other QC

Daily Floods

Unshielded syringes contain average of 30 MBq ^{99m}Tc

9 technicians & 1 physicist

Direct contact and exposure time = 20 seconds

Exposure distance 1 m

Test frequency = 3 cameras, 5 times per week = $3 * 5 * 50 = 750$ /yr

External dose (1 session) = $2.24 \times 10^{-5} * 30 * (20/3600) = 3.73 \times 10^{-6}$ mSv

External dose (per year) = $3.73 \times 10^{-6} * 750/10 = 2.8 \times 10^{-4}$ mSv

Extremity dose (1 session) = $0.354 * 30 * (20/3600) = 0.059$ mSv

Extremity dose (per year) = $0.059 * 750/10 = 4.425$ mSv

There is no contamination, as cap is not removed.

Not volatile form of compound, therefore no internal radiation hazard.

Centre of Rotation

Millennium & Maxxus

2 unshielded syringes containing 20 MBq ^{99m}Tc each (1 per test)

1 physicist

Direct contact and exposure time = 15 seconds
Exposure distance 1 m
Test frequency = 2 cameras, Once per week = 100/yr

External dose (1 session) = $2.24 \times 10^{-5} * 20 * (15/3600) = 1.87 \times 10^{-6}$ mSv
External dose (per year) = $1.87 \times 10^{-6} * 100 = 1.87 \times 10^{-4}$ mSv

Extremity dose (1 session) = $0.354 * 20 * (15/3600) = 0.0295$ mSv
Extremity dose (per year) = $0.0295 * 100 = 2.95$ mSv

There is no contamination, as cap is not removed.
Not volatile form of compound, therefore no internal radiation hazard

Loading 3-point jig Axis CoR

1 shielded syringe containing 900 MBq ^{99m}Tc
1 physicist
Direct contact and exposure time = 30 seconds
Exposure distance 1 m
Test frequency = Once per week = 50/yr
Shield circa 99 % attenuation

External dose (1 session) = $2.24 \times 10^{-5} * 900 * 0.1 * (30/3600) = 1.68 \times 10^{-6}$ mSv
External dose (per year) = $1.68 \times 10^{-6} * 50 = 8.4 \times 10^{-3}$ mSv

Extremity dose (1 session) = $0.354 * 900 * 0.01 * (30/3600) = 0.02655$ mSv
Extremity dose (per year) = $0.02655 * 50 = 1.33$ mSv

Contamination – external dose

Assuming 10 % release onto bench surface during loading of jig, 90 MBq
Small volume, therefore “point source” type spill.
Deep tissue dose rate = 2.61×10^{-4} mSv/h at 30 cm.
Exposure time 30 minutes

External whole body = $2.61 \times 10^{-4} * 90 * (30/60) = 11.75 \times 10^{-3}$ mSv

Contamination – skin dose

Assume 5 % (45 MBq) release onto 25 cm^2 area of skin, i.e. 1800 kBq/cm^2 .
Exposure time 2 minutes
Skin dose rate 0.246 mSv/h (per kBq/cm^2)

Skin dose = $0.246 * 1800 * 2/60 = 14.76$ mSv

Calibrator Linearity test

The test is carried out over 5 days. The activity decays with a half-life of 6.04 hours. An average activity is therefore used calculated by equation 7.4.1.

Equation 7.3.1

$$A_{av} = A_o \left(\frac{\int_{t_1}^{t_2} e^{-\lambda t} dt}{t_2 - t_1} \right)$$
$$= A_o \left(\frac{e^{-\lambda t_1} - e^{-\lambda t_2}}{(t_2 - t_1)\lambda} \right)$$

t1 is the start of the calibration (9 a.m. on the Monday) = 0 hrs

t2 is the end (5 p.m. on the Friday) = 104 hrs

A_o is the initial activity of ^{99m}Tc = 4 GBq

λ = Ln2/T_{1/2}

The average activity for the calibration is therefore 335 MBq

Source is in unshielded, 10 ml P6 vial during measurement.

1 physicist

Direct contact time = 2 minutes (2 seconds per measurement)

Exposure distance = 1 m

Test Frequency = once per year for calibrator in imaging section

External dose (per year) = 2.24x10⁻⁵*335*(2/60) = 2.50x10⁻⁴ mSv

Extremity dose (per year) = 0.354*335*(2/60) = 3.95 mSv

There is no contamination, as vial cap is not removed.

Not volatile form of compound, therefore no internal radiation hazard

Contamination Incident Report

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