A Survey of Nuclear Medicine in the UK in 2003/04

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ABSTRACT

The primary objectives of this survey were

a) to assess trends in the frequency of different nuclear medicine procedures in comparison with the previous national surveys

b) to determine the annual collective effective dose to the UK population from nuclear medicine and the relative contributions of different procedures

c) to review the average activities administered by nuclear medicine departments and compare them with guidance on diagnostic reference levels issued by the Administration of Radioactive Substances Advisory Committee (ARSAC).

The results of this survey show that the total number of procedures performed annually has increased by 36% over the last ten years. 73% of all nuclear medicine administrations are for planar imaging, while SPECT and PET contribute 16% and 2% respectively. Non-imaging diagnostic procedures represent 7% of all nuclear medicine administrations, and therapy 2%. Bone scans continue to be the most frequent procedure. Lung perfusion and myocardial perfusion imaging are also very common procedures. The annual collective effective dose from diagnostic nuclear medicine is about 1600 man Sv (corresponding to a per caput effective dose of about 0.03 mSv). Bone scans are the biggest contributor to collective dose. Planar imaging is responsible for 61% of the total collective effective dose from diagnostic nuclear medicine in the UK, while SPECT, PET and non-imaging contribute 33%, 6% and 0.3% respectively. The activities administered for most procedures adhere closely to those recommended by ARSAC.

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CONTENTS

1 INTRODUCTION

One of the key functions of the Radiation Protection Division of the Health Protection Agency (RPD, formerly the National Radiological Protection Board) is to monitor levels of population exposure from all sources of ionising radiation in the UK, so that RPD can provide advice on radiation protection for the important contributors to the population dose. The assessment of medical exposures represents an important part of the programme of work, and the contribution of medical and dental x-ray examinations to the UK population dose has been reviewed recently (Hart, 2004).

RPD last carried out a thorough national survey of nuclear medicine practice over 20 years ago (Wall, 1985), in collaboration with the British Nuclear Medicine Society (BNMS) and the Hospital Physicist's Association (now the Institute of Physics and Engineering in Medicine, IPEM). A similar survey (Elliott, 1993) was conducted by BNMS and IPEM in 1989/90, showing a 20% increase in imaging studies and a 30% decrease in non-imaging investigations (excluding therapy) over the seven years from 1982 to 1989. No comprehensive national survey has been published since 1990, though there was a partial update (Elliott, 1996) of the 1989/90 survey in 1992-93, a survey of radionuclide therapy (Clarke, 1999) in 1995, several surveys of nuclear cardiology, the latest (Prvulovich, 2002) being for 1997, and a local survey of nuclear medicine practice in the South Thames Health Region (Wells, 1997) in 1996-97.

Over the 1990s there have been substantial changes in nuclear medicine techniques, for example the routine application of single photon emission computed tomography (SPECT) imaging and the introduction of positron emission tomography (PET) into clinical practice. This survey therefore aimed at a comprehensive update of the information available on all diagnostic procedures (imaging and non-imaging) and therapeutic procedures using unsealed radionuclides. The main objectives for the survey were:

1. To establish the major trends in the frequency of different nuclear medicine procedures over the past 13 years and in the radionuclides, administered activities and imaging techniques used.

2. To determine the collective effective dose to the UK population from nuclear medicine and the relative contributions of different procedures.

3. To compare the average activities administered by nuclear medicine departments with the diagnostic reference levels (DRLs) recommended in the Notes for Guidance issued by the Administration of Radioactive Substances Advisory Committee (ARSAC, 1998).

4. To review the makes, types and ages of gamma cameras in current use and their capability for SPECT and PET imaging.

5. To examine staffing levels in radiopharmacies and nuclear medicine departments in the UK.

The survey has been carried out with the support and collaboration of the following organisations:-

Administration of Radioactive Substances Advisory Committee (ARSAC)

British Institute of Radiology (BIR)

British Nuclear Medicine Society (BNMS)

Department of Health (DoH)

Institute of Physics and Engineering in Medicine (IPEM)

Royal College of Physicians (RCP)

Royal College of Radiologists (RCR)

Representatives from all these organisations met at the Department of Health in London on 24 November 2003 to discuss and agree on the methods to be used for carrying out the survey, and subsequently agreed the contents of the questionnaires.

2 METHOD

The survey was conducted by sending two questionnaires, one on nuclear medicine equipment and procedures, and the other on staffing levels, to every nuclear medicine department in the UK. The two questionnaires are shown in Appendices A and B. Two separate questionnaires were prepared because

a) it was expected that a different person with different responsibilities would fill in each questionnaire.

b) the equipment and procedures questionnaire would be analysed at RPD, while the staffing levels questionnaire would be analysed by BNMS.

The staffing levels questionnaire asked about the whole time equivalent numbers of staff of different type and grade working in radiopharmacies and nuclear medicine departments, and some of their responsibilities. The completed staffing levels questionnaires were analysed by representatives of BNMS and the results will be made available elsewhere.

The questionnaire on equipment and procedures asked for details of the imaging and dosimetric equipment that was available in each department and for the numbers of each type of diagnostic investigation or therapeutic treatment performed in the period 1 April 2003 to 31 March 2004. The average activity administered to adult patients for each type of investigation or treatment was also requested. Brief instructions were provided at the beginning of the questionnaire to clarify what was required (see Appendix A). The survey was based on a financial year so that direct comparisons could be made with the English Department of Health's KH12 returns, which are also based on financial years. The KH12 returns (Department of Health, 2004A) give the total number of medical imaging and radiodiagnostic procedures (including nuclear medicine as a separate category) that are performed each year by all NHS trusts in England. The survey was also timed to coincide with the need for hospitals and trusts to compile numbers for the KH12 returns, and thus avoid duplication of effort. The questionnaire was divided into five main sections: equipment;

imaging procedures; PET procedures; non-imaging procedures; and therapeutic procedures with unsealed sources. All of the procedures tabulated in Appendix I of the December 1998 version of the ARSAC Notes for Guidance (ARSAC, 1998) were listed in the questionnaire, apart from brachytherapy procedures with sealed sources. Three new diagnostic procedures, not tabulated in the Guidance Notes but now classed as routine by ARSAC, were also included on the questionnaire. The procedures were primarily listed in accordance with the anatomical region being investigated. The radionuclide and radiopharmaceutical were specified for every procedure. Space was provided in the questionnaire to add any procedure, radionuclide or radiopharmaceutical that was not already listed.

The two questionnaires were e-mailed in April 2004 to every known nuclear medicine centre in the UK, of which there were estimated to be 252, in both the NHS and the private sector. The private sector was not covered in the previous RPD survey (Wall, 1985) of nuclear medicine in the UK, but has been included in this survey, particularly in order to include mobile PET scanner provision. To facilitate comparison with the previous survey, the results for the private sector have mainly been analysed separately from the NHS data in this report.

The list of e-mail addresses to which the questionnaires were sent, was compiled by amalgamating the information provided by:

a) Philip Robinson (RCR)

b) Paul Hinton (IPEM)

c) UK gamma camera data from the year 2000 collected by the National Cancer Services Analysis Team and available on their website at www.canceruk.net

d) A database of Welsh gamma cameras provided by Andrew Ward of Welsh Health Estates in 2004

e) Hospitals and Trusts Directory 2003/04 published by Informa Healthcare

f) IPEM directory of members 2003

g) The names of trusts that gave a KH12 return for nuclear medicine in 2002/03

It was not possible to use any information held by ARSAC, since that information is confidential and only to be used for the purpose of certification.

Those completing the questionnaires were allowed to do so either electronically or manually, depending on their preference. Data providers were assured that information on the performance of each nuclear medicine department would be treated as confidential by RPD, and that reports published by RPD would not identify the results from any specific nuclear medicine department.

The questionnaires were produced in the form of Excel spreadsheets so that they could be sent and returned as e-mail attachments, and to facilitate their transfer into an Excel database. This approach minimised the possibility of transcription errors, which might easily have occurred if the data had been typed into a database (although the few questionnaires that were returned by post had to be manually entered). All data in the database were

checked by the person who entered it, and also by a second person, who had not been involved in entering it.

Once the database was complete, it was quality assured by using the maximum and minimum functions in Excel on all quantitative answers to quickly find the extreme values and check whether they were correctly entered. The database was also checked against data derived from other sources, for instance recent advertisements for jobs in nuclear medicine departments, which often gave information on the available equipment, and on the type and total numbers of procedures performed.

3 RESULTS

A list of the names of all the hospitals which provided data is shown in Appendix C.

3.1 The National Health Service

There are 159 NHS sites in Appendix C, which, compared with the total of 240 NHS sites in the UK that are thought to be performing nuclear medicine, produces a response rate of 66% to this survey. The response rate for the four countries of the UK was: England 66%, Wales 60%, Scotland 65%, Northern Ireland 100%.

3.1.1 Procedures

The total number of nuclear medicine procedures in the UK NHS has been calculated in two ways. Firstly, a simple correction for the percentage of sites not included in this survey (i.e. multiplying the 470,000 NHS procedures notified to us on the questionnaires by 100/66) leads to a total figure of 710,000. However, this estimate assumes that the nuclear medicine workload pattern in the non-responding sample is the same as that in the responding sample. Since a special effort was made to encourage the larger nuclear medicine centres to return their questionnaires, this is unlikely to be true.

Therefore, an estimation of the number of procedures performed at non-responding hospitals was made using the number of gamma cameras recorded at each site in the year 2000 (www.canceruk.net). The 138 hospitals for which the number of gamma cameras was known for both 2000 and 2003/04 showed that the number did not alter significantly between the two dates. Figure 1 shows data from all the responding hospitals and indicates that there is a reasonable correlation (a correlation coefficient of 0.83) between the number of gamma cameras at a site and the total number of procedures (imaging, non-imaging and therapy) that are carried out there. The best linear fit for this correlation was used to estimate the number of procedures performed at non-responding hospitals. Adding the number of procedures notified on questionnaires to the number of procedures estimated for non-responders gave a total of 670,000 for the UK. This was taken to be the best estimate for the total number of procedures in the UK NHS.

This estimate was checked against KH12 returns collected by the English Department of Health. The KH12 returns are amalgamated into NHS Trusts and are not given for individual hospitals. The total number of nuclear medicine procedures in England for 2003/04 was given (Department of Health, 2004A) as 583,000. This can be compared with our estimate of

the number of procedures in England of 544,000, derived, as explained above, partly from the number of gamma cameras at each site. The reason for the discrepancy between the two figures was soon found by checking the KH12 data on a trust by trust basis. There was an obvious mistake in the KH12 return for one trust. The actual number of procedures performed there was about 40,000 less than stated in the KH12 returns. Having made this amendment, the two estimates of the total number of procedures for England are brought into close agreement at 543,000 to 544,000 procedures. The corrected KH12 data thus provide good support for our estimate of the total number of procedures in England, which performs more than 80% of the procedures in the UK.

While there is convincing support for our estimate of the total number of nuclear medicine procedures in the UK, the detailed results presented in this report rely on the assumption that the general pattern of nuclear medicine practice in non-responding hospitals is very similar to that in responding hospitals. This is not an assumption that we could test.

Using the estimate of 670,000 procedures for the UK, the annual number of procedures per 1000 population is about 11, based on a population of 59.6 million in the UK for 2003 (www.statistics.gov.uk). This is significantly higher than the figures derived from previous surveys, which were 6.8 in 1982, and 7.6 in 1989.

Table 1 shows the numbers of imaging, non-imaging and therapy procedures performed in 2003/04 along with numbers from previous surveys for comparison. The number of imaging procedures has increased by 38% over the last 10 years and nearly doubled since 1982. The majority of the imaging procedures (81%) were planar, 17% were performed with SPECT, and 2% were performed with PET. The total number of therapy procedures is probably underestimated because some are carried out in radiotherapy departments, which were not approached in this survey.

FIGURE 1 Relationship between number of gamma cameras and procedures

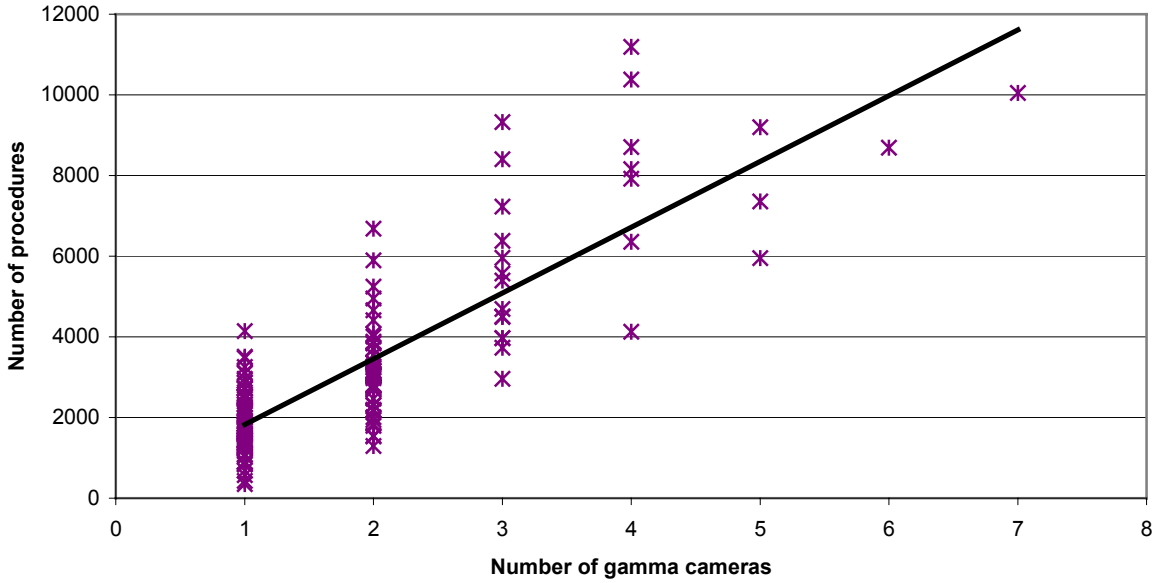


Table 1 Trends in total numbers of procedures in the UK NHS

	Numbers of procedures (thousands per year)			
	1982	1989/90	1992/93	2003/04
Imaging	320	383	443	490 Planar 108 SPECT 12 PET 610 Total 91%
Non-imaging	49	34	35	46 7%
Therapy	11	13	13	14 2%
TOTAL	380	430	491	670 100%

The upper part of Table 2 shows the twenty most frequently performed procedures in 2003/04 and compares the number of administrations for 2003/04 with the number estimated in previous surveys. The final column also shows the percentage of all nuclear medicine administrations (diagnostic and therapeutic) accounted for by each of the top twenty procedures in 2003/04. The lower part of Table 2 shows the eight other procedures which have been in the top twenty in two previous surveys (Wall, 1985; Elliott, 1993). The top twenty procedures make up 92% of the numbers of all administrations currently performed in the UK. As was the case in 1989/90, bone scans using phosphate compounds and lung perfusion using MAA (macro-aggregated albumin) are the two most frequent procedures. However, their frequency has increased, bone scans by 40% and lung perfusion by 86%. Bone scans using phosphate compounds labelled with technetium 99m make up 32% of all imaging procedures (29% of all diagnostic and therapeutic procedures).

Of the twenty most frequently performed procedures listed in Table 2, only six have a diagnostic reference level (DRL) for SPECT (see ARSAC Notes for Guidance). The percentage use of SPECT for those six procedures is indicated in the first column of Table 2. It can be seen that SPECT is mostly used for myocardial studies and is very rarely used for lung perfusion with MAA. It is unclear why 6% of cerebral blood flow studies using exametazime appear to have been performed with a planar technique. The only basis for a non-SPECT study of this type is to check for brain death, which is not a common procedure.

Myocardial perfusion scans using tetrofosmin and sestamibi both appear in the top twenty for the first time. In fact, imaging of the myocardium features more prominently in 2003/04 than it did in 1989/90. Table 2 shows three types of myocardial perfusion scan in the top twenty procedures amounting to 104,000 administrations, whereas in 1989/90 only 12,000 thallium studies of the myocardium featured in the top twenty. Other procedures which appear in the top twenty for the first time are: lung ventilation using DTPA (Diethylene Triamine Pentaacetic Acid); studies of infection, inflammation or tumours using Exametazime; PET scans; and Helicobacter pylori tests. PET appears with 9000 procedures using dedicated PET scanners and fluoro-deoxyglucose (FDG) labelled with ^{18}F to look for tumours. Ulcer-causing H. Pylori bacteria are detected using a breath test involving urea labelled with carbon 14. Apart from cerebral blood flow using Exametazime, brain scans have dropped out of the top twenty. Liver scans using a technetium 99m-labelled colloid have also fallen to very low levels.

Table 2 Trends in numbers of procedures in the NHS

Procedure	Radio-nuclide	Chemical form	Thousands of administrations		
Top twenty procedures			1982	1989	2003/04
					(% of NM)
Bone scan (2% SPECT)	$^{99}Tc^{m}$	Phosphates	92	141	197 (29)
Lung perfusion (0.01% SPECT)	$^{99}Tc^{m}$	MAA	31	51	95 (14)
Myocardium (98% SPECT)	$^{99}Tc^{m}$	Tetrofosmin			63 (9)
Lung ventilation	$^{81}Kr^{m}$	Gas	7	16	41 (6)
Kidney	$^{99}Tc^{m}$	MAG3		9	30 (4)
Kidney	$^{99}Tc^{m}$	DMSA	4	15	29 (4)
GFR measurement	^{51}Cr	EDTA	6	12	23 (3)
Myocardium (87% SPECT)	$^{99}Tc^{m}$	Sestamibi			23 (3)
Lung ventilation	$^{99}Tc^{m}$	DTPA			16 (2)
Myocardium (98% SPECT)	^{201}Tl	Thallous chloride	5	12	16 (2)
Lung ventilation	$^{99}Tc^{m}$	Technegas		13	14 (2)
Thyroid	$^{99}Tc^{m}$	Pertechnetate	17	19	11 (2)
Thyrotoxicosis therapy	^{131}I	Iodide	8	9	10 (2)
Cardiac blood pool	$^{99}Tc^{m}$	Normal erythrocytes	5	12	10 (2)
Tumours (PET)	^{18}F	FDG			9 (1)
Infection, Inflammation, Tumours	$^{99}Tc^{m}$	Exametazime			8 (1)
Helicobacter Pylori test	^{14}C	Urea			7 (1)
Kidney	$^{99}Tc^{m}$	DTPA	16	19	6 (0.9)
Lung ventilation	^{133}Xe	Gas	10	11	6 (0.9)
Cerebral blood flow (94% SPECT)	$^{99}Tc^{m}$	Exametazime		4	5 (0.8)
Procedures formerly in the top twenty					
Vitamin B12 absorption	^{57}Co	Cyanocobalamin	11	5	2
Vitamin B12 absorption	^{58}Co	Cyanocobalamin	7		0.2
Tumours and abscesses	^{67}Ga	Gallium	3		0.9
Liver scan	$^{99}Tc^{m}$	Colloid	49	7	0.3
Thyroid uptake	^{131}I	Iodide	5	3	0.2
Brain scan	$^{99}Tc^{m}$	Pertechnetate	33	8	0.001
Brain scan	$^{99}Tc^{m}$	Gluconate	10	5	0
Brain scan	$^{99}Tc^{m}$	DTPA	7		0
Kidney	^{123}I	Hippuran	4		0

The most frequent non-imaging procedure in Table 2 is the measurement of glomerular filtration rate (GFR) for the kidneys using EDTA, which makes up 52% of all non-imaging procedures. The use of this procedure has approximately doubled in numbers since the survey in 1989/90, when it made up 34% of all non-imaging procedures.

The most frequent therapeutic procedure is iodine 131 treatment for thyrotoxicosis, which makes up 75% of all therapy procedures. Very few departments kept separate statistics on

non-toxic goitre, most included them under thyrotoxicosis. Thyrotoxicosis is a set of conditions (eg Graves' disease, toxic adenoma and toxic goitre) which involve excessive activity of the thyroid. Non-toxic goitre is not associated with excessive activity of the thyroid. Guy's Hospital estimates (Sarah Allen, personal communication) that less than 1% of patients said to have been treated for 'thyrotoxicosis' with iodine 131 would actually have had non-toxic goitre. This is insufficient to make a difference to the listing in Table 2.

All the procedures in Table 2 were listed on the questionnaire that was sent out. The additional imaging procedure that was most commonly inserted in the completed questionnaire (not already being listed in the form sent out) was Sentinel Lymph Node Biopsy. This technique is performed mostly in connection with breast cancer, but is also used for other tumours. The technique uses a nanocolloid labelled with technetium 99m. A total of 359 such procedures were carried out according to the questionnaires that were returned, implying a total of about 550 in the whole of the UK. This is infrequent in comparison with most of the procedures in Table 2. (The use of an intra-operative gamma probe in sentinel lymph node biopsy implies a similar number of non-imaging procedures, compared to the number of imaging procedures. However, these have not been listed in the survey because it was requested on the questionnaire that procedures already recorded under 'Imaging' should not be duplicated in the non-imaging section if they were carried out on the same administered dose.)

There were several listed procedures which had zero returns on the questionnaires. These are shown in Table 3. Additionally, as noted in Table 2, there was only one instance of a brain scan performed with pertechnetate. In some cases in Table 3 the radiopharmaceutical is no longer available; in other cases the very few specialist centres that carry out the procedure were not covered by the survey.

Table 3 Procedures with zero returns on the questionnaires

Procedure	Radionuclide	Chemical form
IMAGING		
Brain	$^{99}Tc^{m}$	DTPA
Brain	$^{99}Tc^{m}$	Gluconate
Cerebral blood flow	^{133}Xe	Saline
Cardiac blood pool	$^{99}Tc^{m}$	Human albumin
GI Tumour	^{111}In	Satumomab (Oncoscint)
Kidney	^{123}I	Hippuran
Lung perfusion	$^{81}Kr^{m}$	Aqueous solution
Myocardium	^{111}In	Imciromab (Myoscint)
Thrombus	^{111}In	Platelets
NON-IMAGING		
Deep vein thrombosis	^{125}I	Fibrinogen
Electrolyte studies	^{22}Na or ^{24}Na	Na+
Total body water	^{3}H	Water
THERAPY		
Arthritis	^{169}Er	Colloid
Malignancy	^{90}Y	Colloidal silicate

The current relative frequencies of different procedures grouped according to the organ or system under investigation are shown in Table 4, along with similar information for the 1982 and 1989/90 surveys. It is clear that investigations of the lungs and cardiovascular system (mainly the heart) have increased substantially. The relative frequency of use of different radionuclides is shown in Table 5, along with such information for the 1982 survey. Similar information for the 1989/90 survey was presented (Elliott, 1996) in terms of the total administered activity, which is not directly comparable with the total number of administrations. Technetium is still the radionuclide of choice for most nuclear medicine procedures.

Table 4 Relative frequency of procedures grouped by organ or system under investigation

	% of total number of administrations		
Organ or system	1982	1989/90	2003/04
Bone	24.5	32.5	29.6
Lung	13.1	21.3	25.6
Cardiovascular	4.5	7.8	16.9
Kidney, urinary system, adrenals	9.5	14.7	13.8
Thyroid/parathyroid	10.2	9.6	5.1
Infection, inflammation, tumours		1.7	3.8
GI Tract	0.8	1.0	2.1
Brain	13.4	5.0	1.0
Haematology	6.6	3.0	0.6
Metabolism	1.2	0.4	0.6
Liver, spleen, pancreas	14.1	2.4	0.5
Other	2.1	0.6	0.4
Total	100	100	100

Table 5 Relative frequency of use of different radionuclides

	% of total number of administrations	
Radionuclide	1982	2003/04
Technetium 99m	75	79.5
Krypton 81m	1.9	6.1
Chromium 51	2.5	3.8
Thallium 201	1.3	2.4
Iodine 131	5.1	2.3
Fluorine 18	--	1.5
Carbon 14	--	1.2
Xenon 133	2.8	0.8
Iodine 123	2.2	0.7
Indium 111	--	0.4
Cobalt 57	2.8	0.3
Iodine 125	1.2	0.3
Cobalt 58	1.8	0.03

Appendix D shows the estimated total annual number of administrations for each of the diagnostic procedures in this survey for both the private sector and the NHS in the UK. Appendix E shows the same information for therapeutic procedures using unsealed radionuclides.

Table 6 Activities administered for the twenty most frequently performed procedures in the NHS

Procedure	Radionuclide	Chemical form	Activity administered (MBq)				
			ARSAC DRL	Mean	Mode	3rd Quartile	Range
Bone scan (planar 98%)	$^{99}Tc^{m}$	Phosphates	600	552	600	600	400-775
(SPECT 2%)			800	682	800	800	500-800
Lung perfusion (planar 99.99%)	$^{99}Tc^{m}$	MAA	100	88	100	100	50-200
(SPECT 0.01%)			200	100	100	100	100-100
Myocardium (SPECT 98%)	$^{99}Tc^{m}$	Tetrofosmin	400	407	400	400	250-600
(planar 2%)	$^{99}Tc^{m}$	Tetrofosmin	300	395	400	400	370-400
Lung ventilation	$^{81}Kr^{m}$	Gas	6000	--	--	--	--
Kidney	$^{99}Tc^{m}$	MAG3	100	89	100	100	20-200
Kidney	$^{99}Tc^{m}$	DMSA	80	77	80	80	23-200
GFR measurement	^{51}Cr	EDTA	3	2.5	3	3	0.2-4
Myocardium (SPECT 87%)	$^{99}Tc^{m}$	Sestamibi	400	403	400	400	388-450
(planar 13%)	$^{99}Tc^{m}$	Sestamibi	300	440	400	500	400-500
Lung ventilation	$^{99}Tc^{m}$	DTPA	80	173	40	80	10-2500
Myocardium (SPECT 98%)	^{201}Tl	Thallous chloride	80	75	80	80	55-80
(planar 2%)	^{201}Tl	Thallous chloride	80	79	80	80	78-80
Lung ventilation	$^{99}Tc^{m}$	Technegas	40	56	20	40	15-300
Thyroid	$^{99}Tc^{m}$	Pertechnetate	80	75	80	80	35-180
Thyrotoxicosis therapy	^{131}I	Iodide	--	462	400	550	185-800
Cardiac blood pool	$^{99}Tc^{m}$	Normal erythrocytes	800	665	800	800	370-800
Tumours (PET)	^{18}F	FDG	400	366	400	400	222-400
Infection, Inflammation, Tumours	$^{99}Tc^{m}$	Exametazime	200	200	200	200	40-600
Helicobacter Pylori test	^{14}C	Urea	0.2	0.1	0.2	0.2	0.01-0.2
Kidney	$^{99}Tc^{m}$	DTPA	300	204	200	233	12-800
Lung ventilation	^{133}Xe	Gas	400	366	200	400	200-600
Cerebral blood flow (SPECT 94%)	$^{99}Tc^{m}$	Exametazime	500	488	500	500	72-800
(planar 6%)	$^{99}Tc^{m}$	Exametazime	500	461	500	500	200-500

3.1.2 Administered activities

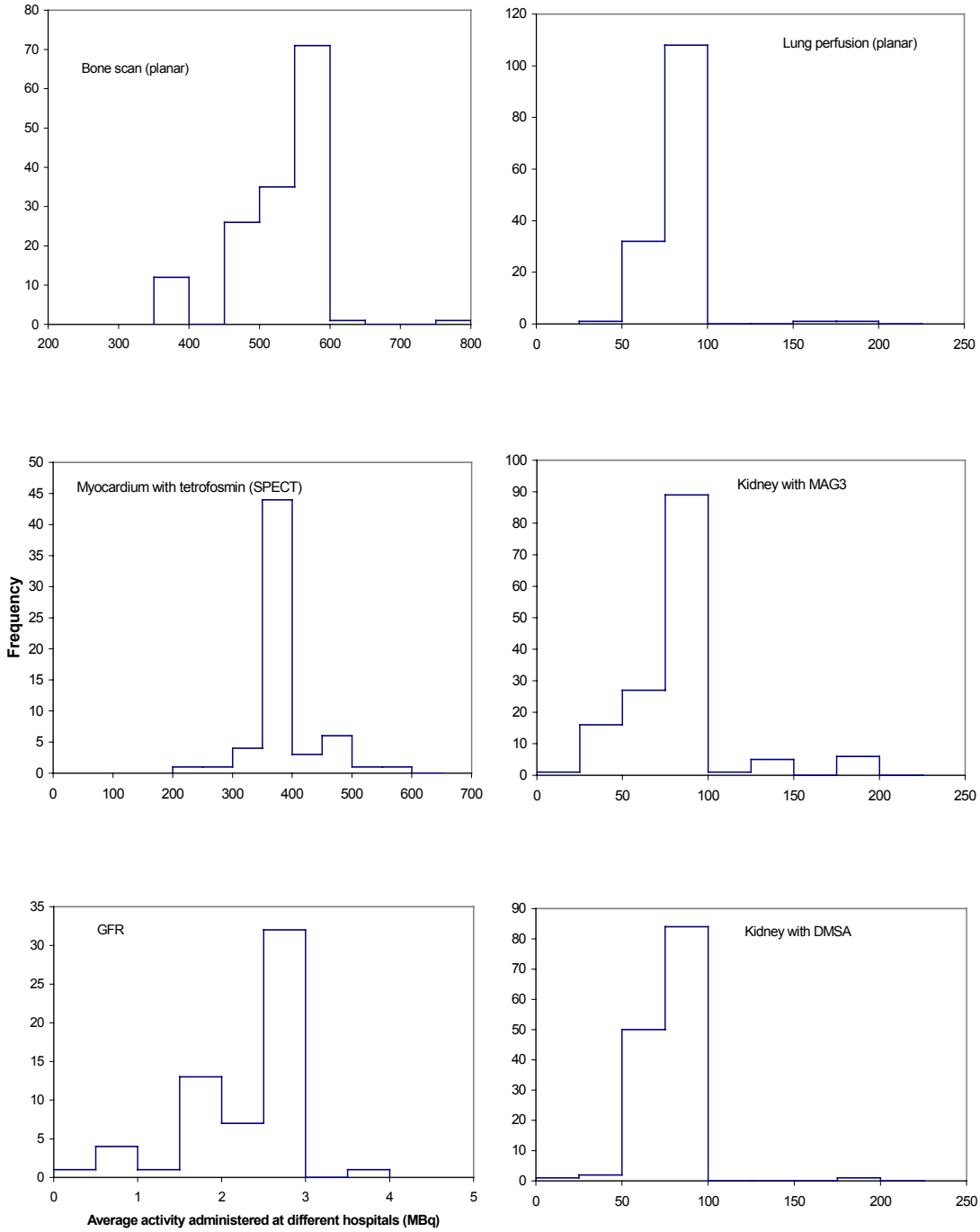
Table 6 shows the distribution of activities administered for the twenty most frequently performed procedures in the NHS. The fourth column of Table 6 lists the diagnostic reference level (DRL) recommended by ARSAC for standard-sized adult patients (ARSAC, 1998). The fifth, sixth and seventh columns give the mean, mode and third quartile of the average activities administered to adult patients at each hospital in the survey. The eighth column of Table 6 gives the range in average activity administered at each hospital from minimum to maximum.

The mean for most procedures in the table is below the DRL, or equal to it. The mode often matches exactly with the DRL, which suggests that most centres adopt the DRL as the activity to use for typical adult patients. For most of the procedures in Table 6 the third quartile value is indistinguishable from the mode. This is due to the tight clustering of the distribution of average activities administered at each hospital around the modal value, as can be seen in the histograms in Figure 2. As a consequence, there is also a close correspondence between the third quartile values and the DRL for most of the procedures in Table 6. The third quartile values observed in national surveys have traditionally been used to establish DRLs for patient doses associated with medical x-ray examinations. However, for diagnostic nuclear medicine procedures the DRLs have been established using the expertise of ARSAC. It is therefore reassuring to find a reasonably close match between these two sets of values.

For lung ventilation studies (apart from those using xenon) the patient breathes in the radionuclide from a reservoir. Our questionnaire did not ask for the activity administered for lung ventilation using krypton 81, on the grounds that it is difficult to estimate the activity actually inhaled by the patient and the effective dose from such a procedure is fairly low, about 0.2 mSv. However, respondents were asked for the activity administered for lung ventilation using DTPA and Technegas because these procedures have a higher effective dose (about 0.4 and 0.6 mSv respectively). In Table 6 these two procedures appear to have a mean administered activity that is above the DRL, and a maximum administered activity that is considerably above the DRL. The most likely explanation for this is that those respondents who have apparently given an activity of more than twice the DRL are probably referring to the amount in the reservoir, while those who have stated an administered activity in the vicinity of the DRL have probably tried to estimate the activity inhaled by the patient.

Two of the myocardial perfusion studies (using tetrofosmin or sestamibi with SPECT) have mean administered activities which are slightly higher than the DRL. There are two factors that explain this. Firstly, these studies are often done with a one-day protocol for which the current SPECT DRL is an average of 500 MBq. Secondly, the ARSAC Notes for Guidance and the procedure guidelines (Anagnostopoulos, 2004) for myocardial perfusion imaging adopted by BNMS and the British Nuclear Cardiology Society state that the administration of activities higher than the DRL can be considered on an individual basis for large patients. As many patients with heart problems are overweight (as seen, for example, in coronary angiography patients in (Hart, 2002)) the average administered activity for myocardial perfusion at any hospital is often likely to exceed the DRL. However, it is noticeable that the planar version of the above studies seems to be undertaken almost entirely at or above the SPECT DRL of 400 MBq rather than the planar DRL of 300 MBq.

FIGURE 2 Distribution of average activity administered



For the four procedures performed mainly with SPECT, the mean activity administered with SPECT is higher than planar for two of them, and lower for the other two. The mean administered activity has therefore not consistently increased through using SPECT.

Eight non-therapeutic procedures (for which the mean administered activity could be estimated) have remained in the twenty most frequent procedures from 1982 to the present. For these procedures it is possible to examine whether there have been any trends in the activity administered over the last two decades, as their mean activities were published in two previous surveys (Wall, 1985; Elliott,1993). The mean administered activities for these procedures are listed in Table 7.

Table 7 Trends in mean administered activity in the NHS

	Mean administered activity (MBq)		
Procedure	1982	1989/90	2003/04
Bone scan (phosphates)	520	545	552 Planar
Lung perfusion (MAA)	88	84	88 Planar
Kidney (DMSA)	102	80	77
GFR (EDTA)	2.8	2.7	2.5
Myocardium (thallium)	68	75	75 SPECT 79 Planar
Thyroid (pertechnetate)	75	85	75
Cardiac blood pool (erythrocytes)	658	722	665
Kidney (DTPA)	248	196	204

For the three procedures involving the kidneys there is a slight indication of a reduction in dose. For planar bone scans there appears to have been a steady rise in the activity administered. Overall it appears that administered activities have remained fairly static.

Appendix D shows the mean of the average administered activities at each hospital for each of the diagnostic procedures in this survey for both the private sector and the NHS in the UK. Appendix E shows the same information for therapeutic procedures using unsealed radionuclides.

3.1.3 Equipment

3.1.3.1 Gamma Cameras

Full details for 267 gamma cameras were supplied on the questionnaires. The average age of gamma cameras was 7.3 years compared with 6.1 years in the 1989/90 survey and with 3.8 years in 1982. 42% of gamma cameras were more than 7 years old, and 25% were more than 10 years old. Two hospitals were still using gamma cameras which were installed in 1984. 52% of gamma cameras have two heads, 46% have one head and 2% have three heads. 74% of gamma cameras are used for SPECT for some part of their time, but only 7% are used for coincident PET (GCPET) for some part of their time.

The average annual number of procedures per gamma camera was calculated by dividing the total number of imaging procedures in the survey (including gamma camera PET, but excluding dedicated PET) by the corresponding total number of gamma cameras. The result, 1580 procedures per year, is compared with data from previous surveys in Table 8, where the number of procedures has been divided by the total number of rectilinear scanners and

gamma cameras during the 1980s. It is clear that the number of procedures per device has increased steadily over the years.

Table 8 Gamma camera provision and use in the NHS

	1982	1989/90	1992/93	2003/04
Estimated number of nuclear medicine sites	288	296	235	240
Estimated total number of gamma cameras	341	316	365	380
Annual number of imaging procedures per gamma camera	922	1211	1307	1580

There is quite a wide range in workload per gamma camera calculated at each hospital. The range goes from a minimum of 382 to a maximum of 3476 imaging procedures per camera.

Table 9 shows the manufacturers' percentage share of gamma cameras in use. Manufacturer's names have been combined where one company has taken over another. GE continues to have the biggest share of the gamma camera market, as it did in 1982 and 1989/90.

Table 9 Manufacturers' percentage share of gamma cameras in use in the NHS

Manufacturer	Number of gamma cameras	%
GE/Elscint/SMV	120	45
Philips/ADAC/Marconi/Picker/Scintronix	66	25
Siemens	62	23
Toshiba	16	6
Park	2	0.8
Mediso	1	0.4
Total	267	100

3.1.3.2 PET scanners

There were 15 dedicated PET (or PET/CT) scanners that were used for clinical or research purposes in 2003/04 in the UK (Department of Health, 2004B). Twelve of these were static and three were mobile. Nine were in the NHS and six in the private sector. The latter are dealt with in section 3.2.

Seven dedicated PET scanners in the NHS were included in this survey, four of these were manufactured by GE and three by Siemens. These scanners were installed over the period 1992 to 2002. 6500 dedicated PET scans in the NHS were notified in this survey. The total of nine dedicated PET scanners in the NHS are therefore estimated to have carried out 8400 PET scans in 2003/04. 90% of all dedicated PET scans involve the same procedure; tumour detection using fluoro-deoxyglucose (FDG) labelled with ^{18}F.

The high cost of dedicated PET (or PET/CT) scanners has led to the use of gamma camera PET systems (GCPET) which are less than half the capital cost, and can also be utilised for the full range of nuclear medicine imaging. GCPET is not as good as a dedicated PET scanner for detecting small cancerous lesions [<10 mm], and their acquisition time is slower. However, GCPET may still have a role to play, perhaps in monitoring the response of tumours to therapy. It has also been argued that it is capable of demonstrating the metastatic spread of breast cancer to the axillary lymph nodes (Mustafa, 2004). The survey

data indicated that 500 GCPET scans were performed in 2003/04; a small number in comparison with 6500 dedicated PET scans. Like dedicated PET, GCPET is used mainly for tumour detection with FDG. Using the same multiplication factor of 1.43 as used in section 3.1.1 to estimate the total number of nuclear medicine procedures in the UK, gives an estimate of 715 GCPET procedures in the whole of the NHS. The total number of PET scans in the NHS (both PET and GCPET) is therefore estimated to be about 9100.

3.1.3.3 Non-imaging (dosimetric) equipment

Table 10 shows the manufacturers' percentage share of non-imaging equipment in use. The non-imaging equipment consisted mainly of various types of beta and gamma counters, including syringe monitors, well counters, radionuclide calibrators and contamination monitors. Details for 217 items of non-imaging equipment were supplied on the questionnaires. Sixteen manufacturers supplied two items or less, so the list has been truncated to name only the top five manufacturers of non-imaging equipment.

Table 10 Manufacturers' percentage share of non-imaging equipment in NHS

Manufacturer	Number of items	%
Canberra/Packard	56	26
EG&G/Ortec/PerkinElmer/Wallac	50	23
Capintec	23	11
Mini-Instruments	14	6
Saint-Gobain/NE/Vinten	14	6
Total	157	72

3.1.4 Radiopharmacies

144 questionnaires on staffing levels were returned. These contained several questions about radiopharmacies, and those which were equipment or procedure-related are analysed here. An analysis of the staffing level information is being performed by BNMS and will be published separately. 51% of the sites in the sample produced technetium radiopharmaceuticals, 33% produced non-technetium radiopharmaceuticals, and 50% labelled blood products. 59.7% of sites performed at least one of these three activities, and thus could be considered to have a radiopharmacy. This percentage may be compared with the statement that 54.9% of departments had an on-site radiopharmacy in the 1992/93 survey (Elliott, 1996).

22% of the sample supplied other hospitals with radiopharmaceuticals. 12% of the sample produced only single doses, either for their own use or for other hospitals, while 40% produced multidose vials (and often single doses as well). For those producing single doses only, the range in the number of doses produced during the period from 01/04/03 to 31/03/04 was from a minimum of 949 to a maximum of 30,000, with an average of 3440. For those producing multidose vials the range in the number of doses was from 800 to 37,500, with an average of 5210. However, some of these sites were counting the number of vials and some were counting the equivalent number of single doses, so these results for multidose producers should be treated with caution.

3.2 The Private Sector

There are 12 sites in the private sector which are known to perform nuclear medicine examinations using their own equipment, including 3 sites in London and its vicinity which have static, dedicated PET scanners only. Six of these sites provided us with information about their equipment and procedures. Two of the sites had a static PET scanner, and two were visited by a mobile PET scanner. [There were three mobile PET scanners in the UK in 2003/04, all of them operated by private companies.] (Department of Health, 2004B)

Another 9 sites in the private sector do not have any nuclear medicine equipment of their own but are known to have been visited by a mobile PET scanner in 2003/04. Five of these sites provided information about the PET scans that were performed. The 11 sites in the private sector that provided information are listed in Appendix C.

3.2.1 Procedures

The number of imaging procedures (excluding PET) listed on the forms returned to us was 3368 for four sites. As in the NHS, bone scans using technetium were easily the most frequent procedure. Assuming there is a total of nine private sites performing conventional nuclear medicine, this implies about 7500 imaging procedures of all types (but excluding PET) being performed annually in the private sector. This is only about 1% of the total performed in the NHS. Looking at the number of non-imaging and therapy procedures does not alter this situation. Only one private hospital performed non-imaging procedures, and only 63 procedures in that case. No private hospital in the survey performed any unsealed radionuclide therapy.

However, the private sector contribution is significant in terms of PET scanning, all of which was performed on dedicated PET scanners. 1700 PET procedures were carried out at the two permanent sites which provided data. Therefore we estimate that about 2500 dedicated PET scans are performed at the three static PET scanners in the private sector. Furthermore, 285 scans were performed using mobile PET scanners at 6 private hospitals. At least a further 5 hospitals were visited by a mobile PET scanner during 2003/04, therefore a total of more than 500 such scans are likely to have been performed. The total number of PET scans performed in the private sector is thus about 3000. Therefore around 25% of all dedicated PET scans in the UK are performed in the private sector. As in the NHS, the overwhelming majority of the PET scans carried out in the private sector were done to detect tumours using FDG labelled with ^{18}F.

3.2.2 Equipment

In addition to the PET scanners mentioned above, details were provided for only four gamma cameras in the private sector. These were installed over the years 1986 to 2001. 75% of these were used for SPECT, and none were used for GCPET. The non-imaging equipment was manufactured sometime during the period 1986 to 1999. Although these are very small samples, it does seem to indicate a similar situation to that in the NHS, where equipment is of a similarly wide range of ages.

3.3 Annual Collective Effective Dose

The collective effective dose from nuclear medicine in the UK for 2003/04 was estimated as follows. For 151 different types of procedure, the mean administered activity in the UK for each type was assumed to be the mean of the average activities reported for all hospitals which performed that procedure in our survey. Coefficients relating effective dose to administered activity were obtained from the addenda to ICRP Publication 53 (ICRP, 1998) and verified by cross-reference to Appendix 1 in the ARSAC Notes for Guidance.

The estimated mean effective dose for a procedure was then multiplied by the estimated total number of each specific procedure in the UK in 2003/04 to give the annual collective dose for that procedure. (The total number for each specific procedure had been estimated by applying the percentage frequency for each procedure in the survey to the total number of procedures that was estimated for the UK in 2003/04.) To estimate the total annual collective dose for the UK was then just a matter of summing across all procedures.

3.3.1 Diagnostic procedures

Using the above method, the total annual collective dose from diagnostic nuclear medicine procedures in the UK NHS and private sector was estimated to be 1588 man Sv. However, in recognition of the fact that we had taken no account of the higher effective doses that were likely to have been given for the small proportion of nuclear medicine procedures carried out on children, this estimate was increased by 2% to 1620 man Sv: see Appendix F. (Appendix F is an attempt to quantify, where possible, the uncertainties in the collective dose from diagnostic procedures. However, there remain some unquantifiable uncertainties, in particular related to the assumption that non-responders have the same activity distributions and mix of procedures as the responders. Therefore the actual overall uncertainty may be greater than that given in Appendix F.)

Table 11 shows the twenty diagnostic nuclear medicine procedures making the largest contribution to collective dose, listed in the order of their contribution. PET, the sixth biggest contributor, includes GCPET. These twenty procedures contribute 94% of the total collective dose from diagnostic nuclear medicine. Four of the procedures listed in Table 11 do not appear in the twenty most frequent procedures listed in Table 2. These four are marked with an asterisk, and appear in Table 11 due to their relatively high mean effective doses. About 4000 examinations of the parathyroid using sestamibi are performed annually, while the other three asterisked procedures are performed 1000 to 2000 times per year.

Table 11 Twenty procedures making the largest contributions to diagnostic collective dose

Procedure	Radio-nuclide	Chemical form	Mean effective dose (mSv)	Collective dose (man Sv)	(%)
Bone scan	$^{99}Tc^{m}$	Phosphates	3.0	601	38
Myocardium	^{201}Tl	Thallous chloride	12.9	209	13
Myocardium	$^{99}Tc^{m}$	Tetrofosmin	3.1	196	12
Myocardium	$^{99}Tc^{m}$	Sestamibi	3.7	92	6
Lung perfusion	$^{99}Tc^{m}$	MAA	0.9	85	5
Tumours (PET)	^{18}F	FDG	7.0	83	5
Cardiac blood pool	$^{99}Tc^{m}$	Normal erythrocytes	4.7	47	3
Cerebral blood flow	$^{99}Tc^{m}$	Exametazime	4.8	24	2
Parathyroid*	$^{99}Tc^{m}$	Sestamibi	5.2	21	1
Kidney	$^{99}Tc^{m}$	DMSA	0.7	20	1
Thyroid metastases after ablation*	^{131}I	Iodide	10.1	19	1
Kidney	$^{99}Tc^{m}$	MAG3	0.6	19	1
Infection, Inflammation, Tumours	$^{99}Tc^{m}$	Exametazime	1.9	15	0.9
Lung ventilation	$^{99}Tc^{m}$	DTPA	0.9	14	0.9
Infection, Inflammation, Tumours*	^{67}Ga	Gallium	13.8	13	0.8
Lung ventilation	$^{99}Tc^{m}$	Technegas	0.8	12	0.8
Infection, Inflammation, Tumours*	^{111}In	Pentetreotide	8.1	11	0.7
Thyroid	$^{99}Tc^{m}$	Pertechnetate	0.9	11	0.7
Lung ventilation	$^{81}Kr^{m}$	Gas	0.2	8	0.5
Kidney	$^{99}Tc^{m}$	DTPA	1.4	8	0.5

* Not listed in Table 2.

3.3.2 Therapeutic procedures

For the first time, we have also made a rough estimate of the collective effective dose from the commonest therapeutic procedures, in order to see how this compares with the collective effective dose from diagnostic procedures. Since the concept of effective dose is based on the addition of probabilities of stochastic effects, it is inappropriate to include doses to the target organs in therapeutic procedures in the calculation of effective dose, as they are so high that cell-killing predominates and the possibility for stochastic effects is eliminated. The effective dose for those therapeutic procedures that use iodine 131 in the form of iodide (thyroid carcinoma, thyrotoxicosis and non-toxic goitre) has consequently been calculated by excluding the dose to the target organ (the thyroid). Table 12 shows that the total annual collective effective dose from these therapeutic procedures is about 742 man Sv, which is about 47% of the total from all diagnostic nuclear medicine procedures.

Table 12 Collective dose from therapeutic procedures using iodine 131 in the form of iodide

Procedure	Radio-nuclide	Chemical form	Mean effective dose (mSv)	Collective dose (man Sv)
Thyroid carcinoma	^{131}I	Iodide	259.0	437
Thyrotoxicosis & non-toxic goitre	^{131}I	Iodide	29.0	305

Appendix D shows the collective effective dose for each of the diagnostic procedures in this survey for both the private sector and the NHS in the UK. Appendix E shows the same information for therapeutic procedures using iodine 131 in the form of iodide.

4 DISCUSSION

It has been assumed for the purposes of this report that the general pattern of nuclear medicine practice in non-responding hospitals is very similar to that in responding hospitals. This is arguably a reasonable assumption given the large size of the sample, the independent corroboration from the KH12 returns of the total numbers of procedures, and the fact that the average activity administered at each hospital is generally concentrated within a narrow range (as exemplified in Figure 2).

There has been an increase of 36% over the last 10 years and 76% over the last 20 years in the annual total number of nuclear medicine procedures performed. The annual number of imaging procedures has increased substantially (by 90% over the last 20 years) while non-imaging and therapy procedures have remained fairly static over the last 20 years, and they continue to be performed much less frequently than imaging procedures. Planar imaging contributes 73% of the numbers of all nuclear medicine administrations, while SPECT contributes 16%, PET 2%, non-imaging 7% and therapy 2%. Planar imaging is responsible for 61% of the total collective dose from diagnostic nuclear medicine in the UK, while SPECT contributes 33%, PET 6%, and non-imaging only 0.3%.

There has been no discernible trend in the activities administered to patients over the last 20 years. It is therefore to be expected that the collective dose would have risen approximately in line with total numbers of procedures. This is indeed the case. The collective effective dose equivalent from nuclear medicine was estimated to be 950 man Sv in 1982 and 1200 to 1400 man Sv in 1990 (Hughes, 1993). Comparing these with our estimate of 1620 man Sv for diagnostic nuclear medicine gives corresponding increases in the collective dose of up to 32% over the last 13 years and 67% over the last 20 years, which roughly match the increases in the total number of procedures. With a UK population of 59.6 million in 2003, the corresponding mean per caput effective dose will be about 0.03 mSv.

The UK collective dose from all x-ray imaging procedures (diagnostic and interventional) in 2001/02 was estimated (Hart, 2004) to be 22,700 man Sv. The contribution to collective

dose from all diagnostic nuclear medicine procedures is therefore about 7% of that from all x-ray imaging procedures.

The annual number of nuclear medicine procedures per 1000 population in the UK is about 11. This is significantly higher than the figures derived from previous surveys, which were 6.8 in 1982, and 7.6 in 1989/90.

Table 13 International comparison of nuclear medicine frequency and collective dose per head

Country	Annual frequency (per thousand population)	Annual per caput effective dose(mSv)
	(Diagnostic & Therapy)	(Diagnostic)
Canada	65	0.16
Germany	34	0.1
USA	32	0.14
Czech Rep	28	
Netherlands	16	0.07
Denmark	15	
Hungary	15	
Sweden	14	
Russia	13	0.08
Australia	12	0.06
Japan	12	
Argentina	11	
Italy	11	
UK	**11**	**0.03**
Finland	10	0.04
Switzerland	10	0.04
Slovakia	9	0.02
New Zealand	8	0.03
Taiwan	7	0.03
Ireland	6	
Ukraine	5	0.01
Portugal	4	
Bulgaria	3	
Romania	3	0.05

Table 13 draws information from UNSCEAR 2000 to make an international comparison of nuclear medicine practice between health-care level I countries (i.e. those having more than one physician per thousand population) (UNSCEAR, 2000). The table compares the UK data with those for other countries on annual frequency per thousand head of population for all nuclear medicine procedures and annual per caput effective dose for diagnostic procedures. The data for all countries other than the UK are from the period 1991-96 and are listed in descending order of annual frequency. Considering that the frequency per head in the UK in 1991-96 was around 8 procedures per thousand population, it is apparent that the UK is well down this list.

5 CONCLUSIONS

The results of this survey show that the total number of procedures performed in the NHS has increased substantially (by 36%) over the last ten years, while there has only been an increase of 4% in the number of gamma cameras over the same period. About 670,000 nuclear medicine procedures of all types were performed in the UK NHS in 2003/04. A further 10,000 procedures were carried out in the private sector. However, these bald numbers do not reveal one way in which the private sector is important: around 25% of all dedicated PET scans in the UK were performed in the private sector. 73% of all nuclear medicine administrations in the NHS are for planar imaging, while SPECT and PET contribute 16% and 2% respectively. The remaining 9% are non-imaging and therapy procedures. Bone scans continue to be the most frequent procedure. Lung perfusion and myocardial perfusion imaging are also very common procedures.

The annual collective effective dose from diagnostic nuclear medicine is about 1600 man Sv for the NHS and the private sector combined. This is about 7% of the corresponding collective dose from all medical x-ray imaging procedures in the UK. Bone scans are the biggest contributor to collective dose. Planar imaging is responsible for 61% of the total collective effective dose from diagnostic nuclear medicine in the UK, while SPECT, PET and non-imaging procedures contribute 33%, 6% and 0.3% respectively. The annual collective effective dose from therapeutic nuclear medicine procedures using iodine 131 (excluding doses to the thyroid) is roughly half of that from all diagnostic procedures.

The mean activities administered by most nuclear medicine centres for most procedures adhere closely to those recommended by ARSAC. Data from UNSCEAR show that in comparison with other health-care level I countries, the UK has a relatively low frequency of nuclear medicine procedures per thousand population and a correspondingly low collective dose per head of population for diagnostic nuclear medicine.

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7 REFERENCES

Anagnostopoulos C et al (2004). Procedure guidelines for radionuclide myocardial perfusion imaging. *Heart*, 90, 1-10.

ARSAC (1998). Notes for guidance on the clinical administration of radiopharmaceuticals and use of sealed radioactive sources.

Clarke SEM, Clarke DG and Prescod N (1999). Radionuclide therapy in the UK in 1995. *Nucl Med Commun*, 20, 711-717.

Department of Health (2004A). Acute services team of the performance analysis branch of the NHS Executive. Imaging and Radiodiagnostics: England, financial year 2003/04. Leeds, Department of Health. [http://www.performance.doh.gov.uk/hospitalactivity/data_requests/imaging_and_radiodiagnostics.htm]

Department of Health (2004B). A framework for the development of PET services in England: a consultation document. [www.dh.gov.uk/Consultations/ClosedConsultations/]

Elliott AT and Shields RA (1993). UK nuclear medicine survey 1989/90. *Nucl Med Commun* 14, 360-364.

Elliott AT, Elliott FM and Shields RA (1996). UK nuclear medicine survey 1992-93. *Nucl Med Commun* 17, 3-7.

Hart D, Hillier MC and Wall BF (2002). Doses to patients from medical x-ray examinations in the UK – 2000 review. Chilton, NRPB-W14.

Hart D and Wall BF (2004). UK population dose from medical x-ray examinations. *Eur J Radiol*, 50, 285-291.

Hughes JS and O'Riordan MC (1993). Radiation exposure of the UK population – 1993 review. Chilton, NRPB-R263.

ICRP (1987). International Commission on Radiological Protection. Radiation dose to patients from radiopharmaceuticals. ICRP Publication 53, *Ann ICRP,* **18**(1-4).

ICRP (1998). International Commission on Radiological Protection. Radiation dose to patients from radiopharmaceuticals. ICRP Publication 80. *Ann ICRP,* **28**(3) is addenda 1 and 2 to ICRP 53. Addenda 3-7 are on ICRP website at www.icrp.org

Mustafa S et al (2004). Double-headed gamma camera PET imaging of the breast. *RAD magazine*, 30 (350), 21-22.

Prvulovich E and Metcalfe MJ (2002). Nuclear cardiology in the UK: activity and practice 1997. *Eur J Nuc Med Mol Imaging*, 29(4), 553-558.

Taylor BN and Kuyatt CE (1994). Guidelines for evaluating and expressing the uncertainty of NIST measurement results. Gaithersburg MD, US Department of Commerce, National Institute of Standards and Technology, Technical Note 1297.

UNSCEAR (2000). United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionising radiation. Volume 1: Sources, Annex D, Medical radiation exposures. New York, United Nations.

Wall BF, Hillier MC, Kendall GM and Shields RA (1985). Nuclear medicine activity in the United Kingdom. *Br J Radiol*, 58, 125-130.

Wells CP, Burwood RJ and Forbes EK (1997). South Thames nuclear medicine survey 1996-97. *Nucl Med Commun*, 18, 1098-1108.

APPENDIX A EQUIPMENT & PROCEDURES QUESTIONNAIRE

A questionnaire should be completed for each hospital that performs nuclear medicine.
The data from this questionnaire will be kept confidential at NRPB and will only be published in a manner that preserves the anonymity of each hospital.

1) Please supply the following details: Person(s) completing questionnaire:

Nuclear medicine centre/Hospital:	Town/City:

The questionnaire is divided into five sections:-

a) Equipment
b) Imaging procedures (Adrenals to Kidney, and Lachryma to Whole Body)
c) PET procedures
d) Non-imaging in-vivo procedures
e) Therapeutic procedures (excluding sealed sources)

Within section b the procedures are arranged alphabetically according to the organ under investigation. All commonly used radiopharmaceuticals are listed. There is space at the end of each section for you to add any procedures or radionuclides that have not been listed.

2) Please state the number of administrations to patients of all ages during 1 April 2003 to 31 March 2004 for each of the diagnostic or therapeutic procedures that were performed at the hospital named above. The actual number of administrations to patients is required, not the total number of preparations, some of which may not have been administered. If 2 investigations are performed on a patient using only 1 administration, then an entry should be made against only 1 of the investigations. Conversely, if a procedure requires 2 separate administrations (eg stress/rest myocardial test) whether of the same or different radionuclides, each administration should be counted separately. However, for lung ventilation imaging, please do not count views separately, even though a fresh quantity of ventilation agent might be used for each view. Typically a lung scan will involve just 2 administrations: 1 for the ventilation imaging and 1 for the perfusion. NB for krypton-81m no estimate of activity is required.

3) Please also state the average administered activity for adults for each type of procedure you perform,
(or the equivalent for a 70kg adult if only children have received administrations).

4) In section (b) the number of administrations and average activity should be given separately for planar and SPECT imaging where appropriate. If precise numbers are not available for the split between planar and SPECT, please enter estimates.

5) **Please return your completed questionnaire by 11th June 2004** as an Excel attachment to an e-mail to: david.hart@nrpb.org
We prefer to receive data in electronic format, because it avoids transcription errors in entering information into our database. But if you have difficulty using this Excel spreadsheet we shall accept a print-out filled in with a pen. Please post your completed print-out to:
Dr David Hart, NRPB, Chilton, Didcot, Oxon OX11 0RQ.
Thank you.

(a) EQUIPMENT 2

Gamma Cameras

Manufacturer	Model	Year of installation	Number of heads	Used for SPECT? (Yes/No)	Combined SPECT/CT?* (Yes/No)	*CT used for attenuation correction? (Yes/No)	Used for Coincident-PET? (Yes/No)	Collimator-PET capable? (Yes/No)

Dedicated SPECT (e.g. HEADTOME, CERASPECT)

Manufacturer	Model	Year of installation	Notes (e.g. for brain studies only)

Dedicated PET Scanners

Manufacturer	Model	Year of installation	PET/CT* (Yes/No)	*CT used for attenuation corr (Yes/No)	Notes (eg date upgraded to PET/CT)

Has a mobile PET scanner been used at your hospital during 1 April 2003 to 31 March 2004?

[ ] Yes/No

Non-Imaging Equipment

Manufacturer	Model	Year of manufacture	Type of Counter (eg automatic beta, gamma probe)

(b) IMAGING PROCEDURES A to K

No. = number of administrations in the period 1 April 2003 to 31 March 2004 — MBq = average administered activity for adults

Organ	ADRENALS		BONE				BRAIN													
			Bone		Bone marrow		Cerebral blood flow						Brain (static)						Cisternography	
Nuclide	131I		99mTc		99mTc		99mTc		99mTc		133Xe		99mTc		99mTc		99mTc		111In	
Chemical form	Iodocholesterol		Phosphates		Colloid		HMPAO Exametazime		ECD		Xe in saline		Pertechnetate		DTPA		Gluconate		DTPA	
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq
Planar																				
SPECT																				

Organ	BRAIN		CARDIOVASCULAR																	
	Parkinsonism		Myocardium										First pass (cardiac) blood flow						Thrombus	
Nuclide	123I		99mTc		201Tl		99mTc		99mTc		111In		99mTc		99mTc		99mTc		111In	
Chemical form	Ioflupane (DaTSCAN)		Sestamibi (Cardiolite)		Tl+		Tetrofosmin (Myoview)		Pyrophosphate		Imciromab (Myoscint)		Pertechnetate		MAG3		DTPA		Platelets	
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq
Planar																				
SPECT																				

Organ	CARDIOVASCULAR										G.I. TRACT									
	Cardiac blood pool				Peripheral vascular						Colonic transit		Meckel scan		GI bleeding		Gastric emptying			
Nuclide	99mTc		99mTc		99mTc		99mTc		99mTc		111In		99mTc		99mTc		99mTc		111In	
Chemical form	Normal erythrocytes		Human albumin		Normal erythrocytes		Human albumin		Pertechnetate		Non-absorbable compounds		Pertechnetate		Colloid or Normal erythrocytes		Non-absorbable compounds		DTPA	
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq
Planar																				
SPECT																				

Organ	G.I. TRACT						KIDNEY													
	GI Tumour		Oesophageal transit		Stomach & salivary gland															
Nuclide	111In		99mTc		99mTc		99mTc		99mTc		99mTc		99mTc		99mTc		123I		123I	
Chemical form	Satumomab (Oncoscint)		Colloid or Non-absorbable compounds		Pertechnetate		DMSA		MAG3 with 1st pass perfusion		MAG3 without 1st pass perfusion		DTPA with 1st pass perfusion		DTPA without 1st pass perfusion		Hippuran with 1st pass perfusion		Hippuran without 1st pass perf.	
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq
Planar																				
SPECT																				

(b) IMAGING PROCEDURES L to W 4

No. = number of administrations in the period 1 April 2003 to 31 March 2004 MBq = average administered activity for adults

Organ	LACHRYMAL DRAINAGE			
Nuclide	99mTc		99mTc	
Chemical form	Pertechnetate		Colloid	
	No.	MBq	No.	MBq
Planar				
SPECT				

Organ	LIVER & SPLEEN					
	Hepatobiliary		Liver/spleen		Spleen	
Nuclide	99mTc		99mTc		99mTc	
Chemical form	HIDA etc		Colloid		Denatured erythrocytes	
	No.	MBq	No.	MBq	No.	MBq

Organ	LUNG				LUNG						LUNG TUMOUR		LYMPH SYSTEM	
	Perfusion				Ventilation									
Nuclide	99mTc		81mKr		99mTc		99mTc		81mKr		133Xe		99mTc		99mTc	
Chemical form	MAA		Aqueous solution		DTPA		Technegas		Gas		Gas		Depreotide (NeoSpect)		Colloid	
	No.	MBq	No.		No.	MBq	No.	MBq	No.		No.	MBq	No.	MBq	No.	MBq
Planar																
SPECT																

Organ	PARATHYROID (single or dual isotope)										THYROID									
											Thyroid				Metastases(after ablation)				Thyroid tumour	
Nuclide	99mTc		99mTc		99mTc		123I		201Tl		99mTc		123I		123I		131I		201Tl	
Chemical form	Sestamibi		Tetrofosmin		Pertechnetate		Iodide		Tl+		Pertechnetate		Iodide		Iodide		Iodide		Tl+	
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq
Planar																				
SPECT																				

Organ	URINARY SYSTEM	
	Direct mict. cyst.	
Nuclide	99mTc	
Chemical form	Pertechnetate	
	No.	MBq
Planar		
SPECT		

WHOLE BODY ---- INFECTION/INFLAMMATION/TUMOURS												
99mTc		99mTc		99mTc		111In		123I		131I		99mTc
Human immuno-globulin		Sulesomab (Leukoscan)		HMPAO exametazime labelled leucocytes		Leucocytes		MIBG		MIBG		Sestamibi
No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq

Organ	WHOLE BODY ---- INFECTION/INFLAMMATION/TUMOURS									
Nuclide	99mTc		99mTc		67Ga		111In		201Tl *	
Chemical form	DMSA		Arcitumomab (CEA)		Ga3+		Pentetreotide (Octreoscan)		Tl+	
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq
Planar										
SPECT										

*To avoid double-counting, thyroid tumours should NOT be included in this category.

	ADDITIONAL IMAGING PROCEDURES															
Organ																
Nuclide																
Chemical form																
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq
Planar																
SPECT																

(c) PET PROCEDURES

6

No. = number of administrations in the period 1 April 2003 to 31 March 2004
MBq = average administered activity for adults

DEDICATED PET SCANNERS

Procedure	Tumours		Myocardium						Bone		Cerebral blood flow		Brain tumour		Parathyroid	
Nuclide	18F		18F		15O		13N		18F		15O		11C		11C	
Chemical form	FDG		FDG		Water		Ammonia		Fluoride		Water		L-methyl methionine		L-methyl methionine	
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq

	Additional Dedicated PET procedures									
Procedure										
Nuclide										
Chemical form										
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq

GAMMA CAMERA PET

Procedure	Tumours		Myocardium	
Nuclide	18F		18F	
Chemical form	FDG		FDG	
	No.	MBq	No.	MBq

	Additional GC PET procedures					
Procedure						
Nuclide						
Chemical form						
	No.	MBq	No.	MBq	No.	MBq

(d) NON-IMAGING IN-VIVO PROCEDURES

Please do not duplicate in this section procedures already recorded in section (b) when carried out on the same administered dose.

No. = number of administrations in the period 1 April 2003 to 31 March 2004 MBq = average administered activity for adults

THYROID						METABOLISM & ABSORPTION									
Thyroid uptake						Vitamin B12 absorption		Vitamin B12 absorption		Bile salt absorption		Bone metabolism		Iron metabolism	
99mTc		123I		131I		57Co		58Co		75Se		47Ca		59Fe	
Pertechnetate		Iodide		Iodide		Cyano cobalamin		Cyano cobalamin		SeHCAT		Ca2+		Fe2+ or Fe3+	
No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq

KIDNEY						HAEMATOLOGY & VASCULAR											
GFR measurement		GFR (no imaging)		Effective renal plasma flow		Deep vein thrombosis		GI blood loss		Plasma volume		Red cell survival		Red cell volume		Sites of sequestration	
51Cr		99mTc		125I		125I		51Cr		125I		51Cr		51Cr	99mTc	51Cr	
EDTA		DTPA		Ortho iodohippurate		Fibrinogen		Normal erythrocytes		Human albumin		Normal erythrocytes		Normal erythrocytes	Normal erythrocytes	Normal erythrocytes	
No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq

MISCELLANEOUS												ADDITIONAL NON-IMAGING IN-VIVO PROCEDURES			
Breath test		H Pylori detection		Electrolyte studies		Electrolyte studies		GI protein loss		Pancreatic studies		Total body water					
14C		14C		22Na		24Na		51Cr		14C		3H					
Glycocholic acid		Urea		Na+		Na+		Cr3+		PABA		Water					
No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq

(e) THERAPEUTIC PROCEDURES (Unsealed sources) 8

No. = number of administrations in the period 1 April 2003 to 31 March 2004
MBq = average administered activity for adults

Disease	THYROID DISEASE						MALIGNANT DISEASE				POLYCYTHAEMIA VERA	
	Carcinoma		Thyrotoxicosis		Non-toxic goitre							
Nuclide	^{131}I		^{131}I		^{131}I		^{131}I		^{90}Y		^{32}P	
Chemical form	Iodide		Iodide		Iodide		MIBG		Colloidal silicate in aqueous solution		Phosphate	
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq

									ADDITIONAL THERAPEUTIC PROCEDURES (Unsealed sources)							
Disease	BONE METASTASES				ARTHRITIC CONDITIONS											
Nuclide	^{153}Sm		^{89}Sr		^{90}Y		^{169}Er									
Chemical form	EDTMP		Chloride (Metastron)		Colloidal silicate in aqueous solution		Colloid									
	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq	No.	MBq

APPENDIX B RADIOPHARMACY & STAFFING QUESTIONNAIRE

RADIOPHARMACY AND NUCLEAR MEDICINE STAFFING LEVELS QUESTIONNAIRE 2003/04 1

BNMS/IPEM/RCP/BIR/RCR/NRPB

This is the second section of a two-part survey endorsed by the organisations listed above. The first section covered equipment and procedures. This section covers staffing levels in nuclear medicine and radiopharmacies. Analysis of this questionnaire will mainly be done by representatives of the professional bodies: BNMS, IPEM and RCP.
A questionnaire should be completed for each hospital that performs nuclear medicine.
This questionnaire may need to be completed or approved by either Trust administrators or clinical directors. Please forward it to the appropriate person if necessary.

1) Please supply the following details:
Person(s) completing questionnaire:

Nuclear medicine centre/Hospital:	Town/City:

2) The abbreviation WTE stands for Whole Time Equivalent
The abbreviation PA stands for Programmed Activities

3) The information provided should be a snapshot of the latest position within the timeframe of this survey i.e. the last full week of March 2004, unless otherwise stated.

4) **Please return your completed questionnaire by 11th June 2004** as an Excel attachment to an e-mail to: david.hart@nrpb.org

We prefer to receive data in electronic format, because it avoids transcription errors in entering information into our database. But if you have difficulty using this Excel spreadsheet we shall accept a print-out filled in with a pen. Please post your completed print-out to:
Dr David Hart, NRPB, Chilton, Didcot, Oxon OX11 0RQ
Any queries on the interpretation of questions included in this form should be addressed to Paul Hinton, chairman of IPEM's Nuclear Medicine Special Interest Group (paul.hinton@nhs.net).

Thank you.

(a) RADIOPHARMACY

All Nuclear Medicine/Radiopharmacy sites

Do you produce technetium radiopharmaceuticals onsite (Yes/No)	
Do you produce non-technetium radiopharmaceuticals onsite (Yes/No)	
Do you label blood products onsite (Yes/No)	

If radiopharmaceuticals are supplied from an offsite radiopharmacy please could you answer the following question

	Designation	Grade
What designation and grade of staff member in your hospital, signs section C of ARSAC form as being responsible for provision of radioactive medicinal products locally		

If technetium and other radiopharmaceuticals are produced onsite please could you answer the following questions

	Designation	Grade	WTE in Radiopharmacy
What designation and grade of staff member is professionally responsible for the Radiopharmacy Service			
What designation and grade of staff member signs section C of ARSAC form as being responsible for provision of radioactive medicinal products			

Do you supply other hospitals (Yes/No)	
Do you have a specials manufacturing licence (Yes/No)	
Are radiopharmaceuticals prepared under Section 10 exemption of the Medicines Act with a pharmacist present (Yes/No)	
If using a Section 10 exemption, what is WTE of pharmacist in Radiopharmacy	

If you have a specials licence what type of staff hold the following positions

	Designation	Grade	Established or Estimated WTE in Radiopharmacy
Quality Control Manager			
Production Manager			

Do you provide multidose vials or single doses (Multi/Single)	
How many doses were produced (01/04/03 - 31/03/04)	

Radiopharmacy Staffing 3

Please include ALL radiopharmacy staff in this section, including those who may have already been mentioned above

	Designation	Grade	Established WTE	Actual WTE	Vacant WTE
Dedicated Radiopharmacy Staff	Pharmacist	B-C			
	Pharmacist	D			
	Pharmacist	E-F			
	Pharmacist	G-H			
	MTO	1 or 2			
	MTO	3			
	MTO	4 or 5			
	Clinical scientist	B 10 and below			
	Clinical scientist	B11-16			
	Clinical scientist	B17-24			
	Clinical scientist	C			
	Other				

Rotational Radiopharmacy Staff who work the rest of the time in pharmacy (eg aseptic services)	Designation	Grade	Number
	Pharmacist	B-C	
	Pharmacist	D	
	Pharmacist	E-F	
	Pharmacist	G-H	
	MTO	1 or 2	
	MTO	3	
	MTO	4 or 5	
	Other		
Approximate total hours per week worked in radiopharmacy by all pharmacy staff			

Rotational Radiopharmacy staff who work the rest of the time in nuclear medicine imaging or medical physics	Designation	Grade	Number
	Radiographer	Senior II	
	Radiographer	Senior I	
	Radiographer	Supt	
	MTO	1 or 2	
	MTO	3	
	MTO	4 or 5	
	Clinical scientist	B 10 and below	
	Clinical scientist	B11-16	
	Clinical scientist	B17-24	
	Clinical scientist	C	
	Other		
Approximate total hours per week worked in radiopharmacy by all nuclear medicine or medical physics staff			

Where staff work mainly in Nuclear Medicine or Medical Physics it is assumed that their time in radiopharmacy is included in the Staff WTE section

(b) STAFFING LEVELS

Consultant Clinical Staff

ARSAC certificate holders	Number in post	Total number of NM/RR PA's per week programmed	Total number of NM/RR PA's actually worked per week	Number of unfilled posts	Consultants retiring in next 5yrs	Consultants retiring between 5 and 10 yrs
Diagnostic - Nuclear Medicine Specialist						
Diagnostic - Radionuclide Radiologist						
Diagnostic - Other (specify)						
Diagnostic - Other (specify)						
Diagnostic - Other (specify)						
Therapeutic - Nuclear Medicine Specialist						
Therapeutic - Radionuclide Radiologist						
Therapeutic - Other (specify)						
Therapeutic - Other (specify)						
Therapeutic - Other (specify)						

Additional consultant clinicians (non-ARSAC certificate holders) who are reporting	Number in post	Total number of NM/RR PA's per week programmed	Total number of NM/RR PA's actually worked per week	Number of unfilled posts	Consultants retiring in next 5yrs	Consultants retiring between 5 and 10 yrs
Nuclear Medicine Specialist						
Radionuclide Radiologist						
Other (specify)						
Other (specify)						
Other (specify)						

Technologist Staff

A post filled by a locum in position for less than one year should be counted as vacant.

Designation	Grade	Established WTE	Actual WTE	Vacant WTE
Radiographer	Senior II			
Radiographer	Senior I			
Radiographer	Supt			
MTO	1 or 2			
MTO	3			
MTO	4 or 5			

Actual onsite support for this site. Where support is provided from another hospital please estimate WTE on this site. If staff from this site support other hospitals, **do not** include time at other centres in these WTE calculations.

Clinical Scientists

Grade	Established WTE	Actual WTE	Vacant WTE
Consultant			
B17-24			
B11-16			
B10 and below			

Who Does What

Please state Yes for Clinical involvement and insert minimum grade for Technologist or Physics involvement.

Task	Clinician	Technologist	Physicist	Notes
Final Clinical Reporting	Yes			
Provisional Clinical Reporting				
Technical Reporting				
Cardiac Stressing				
Benign Therapies				
Malignant Therapies				

APPENDIX C HOSPITALS WHICH PROVIDED DATA

CONTRIBUTING HOSPITALS IN NHS

Aberdeen Royal Infirmary
Addenbrooke's, Cambridge
Altnagelvin, Londonderry
Antrim
Ashford
Ayr
Barnsley District General
Belfast City
Belvoir Park, Belfast
Birmingham Heartlands
Blackburn Royal Infirmary
Blackpool Victoria
Borders General, Melrose
Bradford Royal Infirmary
Bristol Haematology & Oncology Centre
Bristol Royal Infirmary & Children's Hospital
Broomfield, Chelmsford
Charing Cross, London
Cheltenham General
Chesterfield & North Derbyshire Royal
Christie, Manchester
City Hospital, Birmingham
Clatterbridge Centre for Oncology, Wirral
Clinical PET Centre, Guy's & St Thomas'
Colchester General
Conquest, St Leonards-on-Sea
Cookridge, Leeds
Craigavon
Crosshouse, Kilmarnock
Cumberland Infirmary, Carlisle
Darent Valley, Dartford
Darlington Memorial
Derby City General
Derbyshire Royal Infirmary, Derby
Derriford, Plymouth
Diana, Princess of Wales, Grimsby
Dorset County, Dorchester
East Surrey, Redhill
Eastbourne
Essex County, Colchester
Freeman, Newcastle
Frimley Park, Camberley
Furness General, Barrow
Glasgow Royal Infirmary
Glenfield, Leicester
Gloucestershire Royal
Good Hope, Sutton Coldfield
Grantham & District
Great Western, Swindon
Guy's, London
Hammersmith, London
Harrogate District
James Cook University, Middlesbrough

Kent & Canterbury
King's College, London
Leeds General Infirmary
Leicester General
Leicester Royal Infirmary
Lincoln County
Lister, Stevenage
Llandough, Penarth
Luton & Dunstable
Manchester Royal Infirmary
Medway Maritime, Gillingham
Middlesex, London
Monklands, Airdrie
Mount Vernon, Northwood
Musgrove Park, Taunton
Neath Port Talbot
Nevill Hall, Abergavenny
Newcastle General
Ninewells, Dundee
Norfolk & Norwich University
North Manchester General
Northampton General
Northern General, Sheffield
Papworth, Cambridge
Pembury, Tunbridge Wells
Peterborough District
Pilgrim, Boston
Pinderfields General, Wakefield
Poole
Prince Charles, Merthyr Tydfil
Princess of Wales, Bridgend
Princess Royal, Telford
Princess Royal University, Farnborough
Queen Elizabeth the Queen Mother, Margate
Queen Elizabeth, Birmingham
Queen Elizabeth, Gateshead
Queen Elizabeth, Kings Lynn
Queen Elizabeth, Woolwich
Queen's Medical Centre, Nottingham
Queens, Burton-on-Trent
Raigmore, Inverness
Robert Jones & Agnes Hunt Orthopaedic
Rotherham General
Royal Albert Edward Infirmary, Wigan
Royal Berkshire, Reading
Royal Bolton
Royal Bournemouth
Royal Brompton, London
Royal Devon & Exeter
Royal Edinburgh
Royal Free, London
Royal Glamorgan, Llantrisant
Royal Gwent, Newport

Royal Hallamshire, Sheffield
Royal Lancaster Infirmary
Royal Liverpool Children's
Royal London
Royal Preston
Royal Shrewsbury
Royal Sussex County, Brighton
Royal United, Bath
Royal Victoria Infirmary, Newcastle
Royal Victoria, Belfast
Russells Hall, Dudley
Salisbury District
Sandwell General, West Bromwich
Scarborough
Selly Oak, Birmingham
Sheffield Children's
South Tyneside District
Southampton General
Southend
Southern General, Glasgow
Southmead, Bristol
St Bartholomew's, London
St Helier, Carshalton
St James's University, Leeds
St John's, Livingston
St Peters', Chertsey
St Richard’s, Chichester
St Thomas’, London
Staffordshire General, Stafford
Stepping Hill, Stockport
Stobhill, Glasgow
Sunderland Royal
Tameside General, Ashton-under-Lyne
Torbay District General
University Hospital of Hartlepool
University Hospital of North Durham
University Hospital of North Staffordshire
University Hospital of North Tees
University Hospital of Wales, Cardiff
Velindre, Cardiff
Victoria Infirmary, Glasgow
Victoria, Fife
Walsgrave, Coventry
Warrington
West Cumberland, Whitehaven
Western Infirmary, Glasgow
Weston Park, Sheffield
Whiston, Prescot
William Harvey, Ashford
Worcester Royal
Wycombe
Wythenshawe, Manchester
York

CONTRIBUTING HOSPITALS IN PRIVATE SECTOR

Alliance Medical Imaging Centre, London
BMI Alexandra, Cheadle
BMI Bath Clinic
BMI Clementine Churchill, Harrow
BMI London Independent
BMI Priory, Birmingham
BMI Somerfield, Maidstone
BUPA Dunedin, Reading
BUPA Southampton
BUPA Southbank, Worcester
Lister InHealth PET Centre, London

APPENDIX D NUMBERS OF ADMINISTRATIONS, AVERAGE ACTIVITY AND COLLECTIVE DOSE FOR ALL DIAGNOSTIC NUCLEAR MEDICINE PROCEDURES IN UK IN 2003/04

Procedure	Nuclide	Chemical form	Administrations	Average activity	Collective dose
				MBq	man Sv
Dedicated PET					
Tumours	18F	FDG	11160	370.0	78.000
Brain Epilepsy	18F	FDG	109	250.0	0.700
Brain	18F	FDG	72	213.6	0.416
Tumours	18F	FLT thymidine	20	370.0	0.200
Bone	18F	Fluoride	14	229.7	0.097
Myocardium	18F	FDG	13	190.2	0.065
Myocardium	13N	Ammonia	3	550.0	0.006
Tumour	124I	IUDR	3	80.0	0.006
Cerebral blood flow	15O	Water	3	1031.4	0.003
Brain tumour	11C	L-methyl methionine	1	370.0	0.003
Parathyroid	11C	L-methyl methionine	1	370.0	0.003
Prostate	11C		1	370.0	0.003
Oesophagus	11C	Choline	1	370.0	0.003
Myocardium	15O	Water	0	0.0	0.000
Gamma Camera PET					
Tumours	18F	FDG	633	283.8	3.500
Myocardium	18F	FDG	78	149.7	0.313
Myocardium	13N	Ammonia	4	185.0	0.003
IMAGING					
Organ					
ADRENALS	131I	Iodocholesterol	29	26.7	0.341
BONE					
Bone	99mTc	Phosphates	200904	598.3	601.045
Bone marrow	99mTc	Colloid	183	339.6	0.621
BRAIN					
Cerebral blood flow	99mTc	Exametazime	4905	482.9	23.688
Parkinsonism	123I	IBZM or Ioflupane (DaTSCAN)	1594	180.1	6.828
Cerebral blood flow	99mTc	ECD	46	500.0	0.230
Cisternography	111In	DTPA	14	24.0	0.023
Brain (static)	99mTc	Pertechnetate	1	500.0	0.006
Cerebral blood flow	133Xe	Xe in saline	0	0.0	0.000
Brain (static)	99mTc	DTPA	0	0.0	0.000
Brain (static)	99mTc	Gluconate	0	0.0	0.000
CARDIOVASCULAR					
Myocardium	201Tl	Tl+	16197	75.3	209.392
Myocardium	99mTc	Tetrofosmin (Myoview)	63130	406.0	195.973
Myocardium	99mTc	Sestamibi (Cardiolite)	24793	414.2	92.420
Cardiac blood pool	99mTc	Normal erythrocytes	9963	665.1	46.706

Procedure	Nuclide	Chemical form	Administrations	Average activity	Collective dose
				MBq	man Sv
Peripheral vascular	99mTc	Normal erythrocytes	661	650.0	4.296
First pass (cardiac) blood flow	99mTc	Pertechnetate	263	676.8	2.223
Myocardium	99mTc	Pyrophosphate	308	608.4	0.937
Peripheral vascular	99mTc	Pertechnetate	42	487.5	0.254
First pass (cardiac) blood flow	99mTc	DTPA	27	350.0	0.060
First pass (cardiac) blood flow	99mTc	MAG3	17	300.0	0.026
Peripheral vascular	99mTc	Human albumin	3	40.0	0.001
Myocardium	111In	Imciromab (Myoscint)	0	0.0	0.000
Thrombus	111In	Platelets	0	0.0	0.000
Cardiac blood pool	99mTc	Human albumin	0	0.0	0.000
G.I. TRACT					
Meckel scan	99mTc	Pertechnetate	1212	293.9	4.453
GI bleeding	99mTc	Colloid or Normal erythrocytes	632	412.7	2.609
Gastric emptying	99mTc	Non-absorbable compounds	1493	14.0	0.522
Colonic transit	111In	Non-absorbable compounds	183	8.1	0.493
Gastric emptying	111In	DTPA	184	8.0	0.441
Stomach & salivary gland	99mTc	Pertechnetate	464	53.4	0.310
Oesophageal transit	99mTc	Colloid or Non-absorbable compounds	325	27.2	0.199
GI Tumour	111In	Satumomab (Oncoscint)	0	0.0	0.000
KIDNEY					
Kidney	99mTc	DMSA	29207	77.4	19.781
Kidney	99mTc	MAG3 without 1st pass perfusion	17423	79.0	9.637
Kidney	99mTc	MAG3 with 1st pass perfusion	12907	102.2	9.231
Kidney	99mTc	DTPA without 1st pass perfusion	3715	180.9	4.480
Kidney	99mTc	DTPA with 1st pass perfusion	1891	248.7	3.135
Kidney	123I	Hippuran with 1st pass perfusion	0	0.0	0.000
Kidney	123I	Hippuran without 1st pass perf.	0	0.0	0.000
LACHRYMA					
Lachrymal drainage	99mTc	Pertechnetate	278	13.9	0.048
Lachrymal drainage	99mTc	Colloid	367	6.6	0.024
LIVER & SPLEEN					
Hepatobiliary	99mTc	HIDA etc	2733	121.6	4.431
Liver/spleen	99mTc	Colloid	326	98.3	0.321
Spleen	99mTc	Denatured erythrocytes	24	66.7	0.033
LUNG					
Lung Perfusion	99mTc	MAA	95558	88.6	84.658
Lung Ventilation	99mTc	DTPA	16321	173.0	13.894
Lung Ventilation	99mTc	Technegas	14464	56.0	11.919
Lung Ventilation	81mKr	Gas	40535	6000.0	8.000
Lung Ventilation	133Xe	Gas	5570	366.4	2.041
Lung tumour	99mTc	Depreotide (NeoSpect)	275	647.6	1.781
Lung Perfusion	81mKr	Aqueous solution	0	0.0	0.000
LYMPH SYSTEM	99mTc	Colloid	2321	44.3	1.029

Procedure	Nuclide	Chemical form	Administrations	Average activity	Collective dose
				MBq	man Sv
PARATHYROID					
Parathyroid	99mTc	Sestamibi	3934	575.6	20.541
Parathyroid	201Tl	Tl+	158	71.5	2.547
Parathyroid	123I	Iodide	484	17.5	1.693
Parathyroid	99mTc	Pertechnetate	1236	64.9	1.002
Parathyroid	99mTc	Tetrofosmin	24	433.5	0.106
THYROID					
Metastases(after ablation)	131I	Iodide	1922	169.0	19.493
Thyroid	99mTc	Pertechnetate	11500	74.6	10.718
Thyroid	123I	Iodide	708	18.4	2.613
Thyroid tumour	201Tl	Tl+	62	77.5	1.080
Metastases(after ablation)	123I	Iodide	194	181.4	0.441
URINARY SYSTEM					
Direct micturating cystogram	99mTc	Pertechnetate	334	65.0	0.261
INFECTION/INFLAMMATION/TUMOURS					
Whole body	99mTc	EXAMETAZIME labelled leucocytes	7979	199.8	14.829
Whole body	67Ga	Ga3+	926	136.3	12.746
Whole body	111In	Pentetreotide (Octreoscan)	1410	150.9	11.476
Whole body	111In	Leucocytes	990	19.9	7.051
Whole body	99mTc	Sulesomab (Leukoscan)	1238	690.5	6.841
Whole body	123I	MIBG	1276	298.7	5.716
Whole body	201Tl	Tl+	65	125.0	1.998
Whole body	99mTc	Sestamibi	202	772.0	1.902
Whole body	99mTc	DMSA	204	339.4	0.521
Whole body	131I	MIBG	76	24.0	0.275
Whole body	99mTc	Arcitumomab (CEA)	20	744.4	0.140
Whole body	99mTc	Human immunoglobulin	3	202.5	0.009
ADDITIONAL IMAGING PROCEDURES					
Prostate	111In	Prostascint	71	185.0	3.263
Tumour	In-111	Lanreotide	23	220.0	1.267
Thyroid- Mets pre-ablation	131I	Sodium Iodide	222	40.0	0.532
Breast	99mTc	Tetrofosmin (Myoview)	68	740.0	0.501
Whole body	In-111	Platelet survival	37	16.7	0.312
Brain tumour	201Tl	Chloride	9	100.0	0.213
Breast Sentinel Node	99mTc	Colloid	517	35.5	0.184
Brain	123I	5-iodo-3- etidinylmethoxy pyridine	43	185.0	0.120
Proctogram	99mTc	DTPA	176	96.7	0.113
Lung Permeability	99mTc	DTPA	225	80.0	0.090
GI Bleed	111 IN	LABELLED RBCs	13	19.0	0.082
Lung	99mTc	NC100668 Thrombus imaging	9	740.0	0.064
Indirect cystogram	99mTc	MAG3	111	65.0	0.050
Adrenal	123I	MIBG	13	236.7	0.046
Tumour	99mTc	Annexin	3	800.0	0.023

Procedure	Nuclide	Chemical form	Administrations	Average activity	Collective dose
				MBq	man Sv
Amyloidosis	99mTc	Aprotinin(Trasylol-Bayer)	10	200.0	0.020
Kidney	99mTc	DTPA with 1st pass – Kidney transplant	7	400.0	0.019
Liver	99mTc	Labelled erythrocytes	4	350.0	0.015
Liver Lung shunt	99mTc	MAA	6	125.0	0.007
Peritoneum	99mTc	Colloid or DTPA	14	69.7	0.007
Leg DVT	99mTc	MAA	7	75.0	0.005
Gastric empty	99mTc	Tin Colloid	13	12.0	0.004
Oesophageal Transit	99mTc	DTPA	7	20.0	0.001
Lymph	99mTc	HIG	3	20.0	0.001
Small Bowel Transit	99mTc	MAA	1	12.0	0.000
Nasal transit	99mTc	HSA	10	1.0	0.000
NON_IMAGING					
THYROID					
Thyroid uptake	131I	Iodide	158	0.5	2.313
Thyroid uptake	99mTc	Pertechnetate	508	99.3	0.631
Thyroid uptake	123I	Iodide	366	4.0	0.295
METABOLISM & ABSORPTION					
Bile salt absorption	75Se	SeHCAT	1732	0.5	0.681
Vitamin B12 absorption	57Co	Cyano cobalamin	2012	0.0	0.163
Vitamin B12 absorption	58Co	Cyano cobalamin	173	0.0	0.026
Iron metabolism	59Fe	Fe2+ or Fe3+	3	0.4	0.012
Bone metabolism	47Ca	Ca2+	1	1.0	0.002
KIDNEY					
GFR (no imaging)	99mTc	DTPA	4272	12.0	0.431
GFR measurement	51Cr	EDTA	23250	2.5	0.116
Effective renal plasma flow	125I	Ortho iodohippurate	158	0.5	0.001
HAEMATOLOGY & VASCULAR					
Red cell volume	51Cr	Normal erythrocytes	1672	0.9	0.534
Plasma volume	125I	Human albumin	1531	0.2	0.087
GI blood loss	51Cr	Normal erythrocytes	33	4.2	0.035
Sites of sequestration	51Cr	Normal erythrocytes	12	3.5	0.010
Red cell survival	51Cr	Normal erythrocytes	16	1.3	0.006
Red cell volume	99mTc	Normal erythrocytes	256	1.7	0.004
Deep vein thrombosis	125I	Fibrinogen	0	0.0	0.000
MISCELLANEOUS					
H Pylori detection	14C	Urea	6512	0.1	0.094
GI protein loss	51Cr	Cr3+	109	1.5	0.012
Breath test	14C	Glycocholic acid	664	0.2	0.001
Pancreatic studies	14C	PABA	81	0.2	0.001
Electrolyte studies	22Na	Na+	0	0.0	0.000
Electrolyte studies	24Na	Na+	0	0.0	0.000
Total body water	3H	Water	0	0.0	0.000

Procedure	Nuclide	Chemical form	Administrations	Average activity	Collective dose
				MBq	man Sv
ADDITIONAL NON-IMAGING IN-VIVO PROCEDURES					
Platelet localisation	111In	Platelets	6	16.0	0.048
GI protein loss	111In		1	5.0	0.001
GI absorption	51Cr	EDTA	65	3.7	0.000
Breath test (fat malabsorption)	C14	Glycerol trioleate (Triolein)	49	0.2	0.000
H Pylori detection	13C not active		1871	0.0	0.000
Pancreatic function	13C	Mixed Triglyceride	39	0.0	0.000
		TOTAL	665727		1588

APPENDIX E NUMBERS OF ADMINISTRATIONS, AVERAGE ACTIVITY AND COLLECTIVE DOSE FOR THERAPEUTIC NUCLEAR MEDICINE PROCEDURES IN UK IN 2003/04

Procedure	Nuclide	Chemical form	Administrations	Average activity	Collective dose*
				MBq	man Sv
THERAPY					
THYROID DISEASE					
Carcinoma	^{131}I	Iodide	1692	4197.9	437
Thyrotoxicosis	^{131}I	Iodide	10423	461.9	296
Non-toxic goitre	^{131}I	Iodide	261	542.7	9
MALIGNANT DISEASE	^{131}I	MIBG	156	7450.0	
	^{90}Y	Colloidal silicate	0	0.0	
POLYCYTHAEMIA VERA	^{32}P	Phosphate	184	186.1	
BONE METASTASES	^{153}Sm	EDTMP	94	2711.3	
	^{89}Sr	Chloride (Metastron)	480	154.5	
ARTHRITIC CONDITIONS	^{90}Y	Aqueous colloidal silicate	330	185.9	
	^{169}Er	Colloid	0	0.0	
ADDITIONAL THERAPEUTIC PROCEDURES (Unsealed sources)					
Thyroid Ablation	^{131}I	Sodium Iodide	114	3500.0	
Lymphoma, Anti-B1	^{90}Y	Zevalin Ibritumomab	13	1000.0	
Liver cancer	90Y	SIR Spheres Liver	7	2000.0	
Carcinoid	90Y	Lanreotide DOTA Somatostatin	86	1200.0	
Bone pain	186Re	HEDP	7	1295.0	
Neuroblastoma	90Y	Dotatoc	39		
Antibody therapy	^{131}I		75		
Hepatic tumour	^{131}I	Lipiodol	9	1100.0	
Thrombocythaemia	^{32}P	Phosphate	1	110.0	
		TOTAL	13969		742

* excluding the very high doses to the thyroid

APPENDIX F UNCERTAINTIES IN DIAGNOSTIC COLLECTIVE DOSE

To estimate the total overall uncertainty in our estimate of the collective dose requires an assessment of the systematic and random uncertainties inherent in the methods used to determine both the frequencies and the mean effective doses for the nuclear medicine procedures.

Systematic uncertainties in the frequency data will be mainly related to any bias in the sample of nuclear medicine centres included in the survey. With a 100% sample obtained for the survey in Northern Ireland, (see section 3.1) the systematic uncertainty in that data will be effectively zero. A 66% sample was obtained for England but the total number of procedures estimated for England from this survey matched those from the KH12 returns (which are intended to be a 100% sample) to within 0.2%. We can therefore assume that the systematic uncertainty in our estimate of the frequency for each type of nuclear medicine procedure in England will be no more than 1% with a fair degree of confidence (corresponding to the 95% confidence limit). This estimate can also be applied to Wales and Scotland, since the survey samples were of a similar size in these two countries to that in England (60% and 65% respectively).

We cannot assess the random uncertainties in the frequency data without repeating the survey many times and observing the variation in response to each question. However, if exactly the same survey were carried out again, one would expect to receive exactly the same answers most of the time with perhaps small differences occasionally, if different people were interpreting the questions and searching for the data each time. We are therefore probably justified in assuming that the random uncertainty in the total numbers of each type of procedure in the UK is likely to be no more than ±1% at the 95% confidence level. The exact evaluation of this uncertainty is not crucial because the overall uncertainty on the collective dose, as we shall see, is dominated by the uncertainties in the mean effective doses and not in the frequencies.

The combined (random + systematic) uncertainty in the frequency of nuclear medicine procedure N is given by adding in quadrature the standard systematic and random uncertainties, where the “standard” uncertainties are the uncertainties at the 95% confidence level divided by 2, i.e. -

$$U_R(F_N) = \sqrt{(0.5^2 + 0.5^2)} = 0.71\%$$

Since our estimates of the mean effective dose for each procedure were derived from the average administered activities reported by each hospital, the random uncertainty in our estimates can be determined from the standard error on the mean of the average activities. For the 20 procedures that make the biggest contribution to collective dose (totalling 94%), the standard error on the mean activity ranges from 1.2% to 36.4%, with an average value of 4.9%.

There are at least two sources of systematic uncertainty in the effective dose estimates to be considered. One is the uncertainty in the coefficients used to derive effective dose from the

activity used. The other is that we have taken no account of the fact that the effective dose given to children will differ from that to adults.

In discussing the uncertainties in the dose coefficients, ICRP Publication 53 (ICRP, 1987) estimates that the coefficients for converting administered activity into effective dose (equivalent) could vary within a factor of two for individual patients. This is due to differences in physique and metabolism for specific patients when compared to the standard phantom used in the ICRP modelling. However, for the purpose of calculating the collective dose, we are interested in the average effective dose for an average patient given the average activity found in the survey. Since the ICRP models are based on an average physique and metabolism, the resultant systematic uncertainties for a collective effective dose estimate should be very small. Moreover, since most other researchers will use the same coefficients to calculate effective doses, there should be no systematic differences from this source between the estimates of collective dose made for different countries. We will therefore ignore the systematic uncertainty arising from the dose coefficients.

We did not collect any information about the activity administered to paediatric patients, and therefore assumed they received the same effective doses as adults. This assumption leads to an underestimation of the total collective dose if the recommendations for the activity to be administered to children in the ARSAC Notes for Guidance are being followed. This is because, in order to maintain the same count density as for an adult patient, the recommended fraction of the adult administered activity is not decreased as much as the child's fraction of the adult weight (taken to be 70 kg). The resulting effective dose for babies would then be approximately twice that for adults, while 8 year old children weighing 26 kg would have a 50% higher effective dose than adults weighing 70 kg. However, UNSCEAR data for Healthcare Level I countries showed that during 1991-96 only 5% of all diagnostic nuclear medicine procedures were carried out on patients under 16 years of age[17], and very few of these were carried out on babies. The underestimation in our total collective dose is therefore likely to be less than 3%. We will consequently increase our estimate by 2% to 1620 man Sv and ascribe a remaining symmetrical systematic uncertainty of ±1% at the 95% confidence level to this estimate.

The combined (random + systematic) uncertainty in the mean effective dose estimate for nuclear medicine procedure N is given by adding in quadrature the standard systematic and random uncertainties, i.e.-

$$U_R(E_N) = \sqrt{(SEOM_N^2 + 0.5^2)}$$

where SEOM = the standard error on the mean of the average administered activities reported by each hospital.

Since the collective dose for each procedure is the product of the frequency and the mean effective dose, the standard uncertainty on the collective dose for each procedure was calculated by combining the relative (percentage) combined standard uncertainties for each procedure according to equation 1 (Taylor, 1994):-

$$[U_R(CD_N)]^2 = [U_R(F_N)]^2 + [U_R(E_N)]^2 \quad (1)$$

where $U_R(CD_N)$ is the relative uncertainty on the collective dose for procedure N, and the other two terms are the relative combined uncertainties for the frequency and the mean effective dose for that procedure.

Since the total collective dose is the sum of the collective doses for each procedure, the standard uncertainty on the total collective dose was calculated by combining the absolute combined standard uncertainties on the collective dose for each procedure according to equation 2 (Taylor, 1994):-

$$[U_A(CD)]^2 = [U_A(CD_1)]^2 + [U_A(CD_2)]^2 + \ldots + [U_A(CD_N)]^2 \quad (2)$$

where $U_A(CD)$ is the absolute standard uncertainty on the total collective dose, $U_A(CD_1)$ is the absolute uncertainty on the collective dose for procedure 1, etc.

If the top 20 procedures that contribute 94% of the total collective effective dose are included in equation 2, we can obtain a good estimate of the standard uncertainty in the total collective dose from all diagnostic nuclear medicine procedures. This estimate is then multiplied by two to obtain the overall uncertainty at the 95% confidence level. This resulted in an overall uncertainty at the 95% confidence level of $\pm$28 man Sv, or $\pm$2%.