Doses to Patients from Medical X-ray Examinations in the UK – 2000 Review

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ABSTRACT

In 1992 NRPB established a National Collation Centre for measurements of doses to patients made by x-ray departments throughout the UK. This report is the second in a series of five-yearly reviews of the national patient dose database and analyses the information collected during the period January 1996 to December 2000. It includes the results of 28,000 entrance surface dose (ESD) measurements and 13,000 dose-area product (DAP) measurements for single radiographs, and 140,000 DAP measurements and 128,000 records of the fluoroscopy time for complete examinations, collected from 371 hospitals throughout the UK. Information on the patient dose distributions and exposure conditions for over 30 types of examination and radiograph is presented. National reference doses based on the rounded third quartile values of these dose distributions are recommended and are seen to be about 20% lower than corresponding values in the previous (1995) review. They have approximately halved since the original UK national reference doses were derived from a survey in the mid-1980s. In this review reference doses have been derived for a larger number of examinations on adults than previously and, for the first time, for three examinations on children, with specific values for five standard-sized patients corresponding to new born babies, 1, 5, 10 and 15 year olds.

NRPB gratefully acknowledges the co-operation of hospital physicists and radiology department staff in supplying patient dose data. The continued provision of data to the National Patient Dose Database will be essential in order to monitor the progress of patient dose reduction measures in the UK and to extend and revise national reference doses in the future.

Chilton
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Approval: May 2002
Publication: June 2002
£15.00
ISBN 0 85951 485 4

CONTENTS

1 INTRODUCTION

After the publication of a *National Protocol for Patient Dose Measurements in Diagnostic Radiology*[1] in 1992, NRPB established a National Patient Dose Database (NPDD) to collate the doses being measured to patients from routine x-ray examinations in hospitals throughout the UK. A review of the data collected up to the end of 1995 was published as an NRPB report[2] in 1996. This current report continues the review process by analysing the data collected during the subsequent five-year period from January 1996 to December 2000. It is our intention to continue to publish reviews of the NPDD every five years.

In the past, NRPB, in consultation with the relevant professional bodies, has provided guidance on national reference doses for common x-ray examinations, based on rounded third quartiles of patient doses observed in national surveys[1,3,4]. In the 1995 review[2] of the NPDD, third quartile values were tabulated that were on average 34% lower than those in the earlier national survey[5] that formed the basis for the original national reference doses. However, they were not, at the time, quoted as new national reference doses since it was recognised that consultation with the relevant professional and regulatory bodies would be necessary before any formal recommendations could be made. The Ionising Radiation (Medical Exposure) Regulations [IR(ME)R][6], which came into force in 2000, provided a new legal framework for the establishment of reference doses or 'diagnostic reference levels' (DRLs) as they are referred to in the new regulations. A Department of Health (DH) Working Party, with representatives from all professional, advisory and regulatory bodies involved in radiology, decided in January 2000 that the rounded third quartile values from NRPB's 1995 review of the NPDD should be used for new national DRLs[7] as required by IR(ME)R. The DH DRL Working Party also agreed that DRLs at the national level should be reviewed every five years. NRPB's planned five-yearly reviews of the NPDD would be an important source of data that would be considered by the DH Working Party when reviewing national DRLs. Consequently, in this report (and in all subsequent 5-yearly reviews) NRPB will continue to give guidance on 'national reference doses' based on the third quartile values observed for patient dose distributions in the current review of the NPDD. The DH (through its DRL Working Party) can then decide which of these recommended 'national reference doses' will be adopted as 'national DRLs' in accordance with IR(ME)R requirements.

The patient doses entered into the NPDD have predominantly been expressed in terms of the quantities entrance surface dose (ESD) for individual radiographs and dose-area product (DAP) for complete examinations. These were the dose quantities recommended in the *National Protocol*[1] in 1992, as being easy to measure with readily available dosemeters of sufficient accuracy. However, the use of DAP meters has become more widespread in the UK over the past few years, and they are increasingly being installed on radiographic as well as

fluoroscopic imaging equipment. Many hospitals have found it easier to take measurements of DAP per radiograph than ESD per radiograph. This report consequently contains an analysis of these DAP per radiograph measurements (as well as ESD per radiograph), which were not featured in the previous review[2]. Since guidance from the Department of Health[8] suggests that fluoroscopic screening time can be used as a relevant quantity in which to express diagnostic reference levels for fluoroscopic x-ray examinations, this report includes an analysis of the data on fluoroscopy times as well as DAPs for complete examinations.

The 1992 *National Protocol*[1] did not provide guidance on the special dosimetric methods required for measuring patient doses from computed tomography (CT) examinations. Consequently, data for CT have not been included in the NPDD in the past and there are no analyses of CT patient doses in this current review. However, NRPB is planning a new national survey of CT practice for 2002/03 and intends to set up a new database specifically for CT in the near future.

Now that there is a legal requirement for every radiology department to establish DRLs, there is a need to make data available on nationally representative patient dose distributions for as many different types of radiograph and examination as possible. Each radiology department would then have a wider range of examinations from which to choose those most appropriate for its own practice when establishing DRLs locally. Fortunately, over the current review period, data on patient doses and examination technique have been received for many more types of examination than in the 1995 review. The data have been selected and analysed so as to provide useful information on the dose distributions associated with as wide a range of radiographs and examinations as can be clearly specified in terms of anatomical location, and for which a large enough sample size is available for it to provide a reasonable indication of national practice. Data for both adult and paediatric patients have been analysed, leading to the formulation of recommended national reference doses for over twenty types of x-ray examination on adults and three types of examination on children.

The technical information stored in the database on the x-ray imaging equipment and the examination techniques has been studied to see if any factors can be clearly identified as having a significant impact on patient dose. Also, comparisons have been made between the dose distributions seen in this review and those seen in previous reviews and surveys, to assess national trends in patient doses since the mid 1980s.

2 DISTRIBUTION OF DATA SAMPLE

2.1 Sources of data

Data were obtained through three main routes:

1. A continuous supply of data throughout 1996-2000 following the request in the National Protocol (25%).

2. Responses to a letter sent in July 2000 to over 50 medical physicists throughout the UK with an interest in patient dosimetry in diagnostic radiology (70%).

3. Measurement of entrance surface doses by NRPB's Patient Dosimetry Service (PDS) throughout 1996-2000 (5%).

Although the invitations to supply data through routes 1 and 2 were addressed to the entire diagnostic radiology community in the UK, this was a voluntary exercise and those who responded were essentially a self-selected group. Respondents were assured that any data they submitted would be treated confidentially, would not be passed to any third party and that it would be impossible to identify the performance of individual hospitals in any published reviews of the database. Despite this assurance, it is possible that a few hospitals might withhold data if they knew their doses to be exceptionally high, for example. Consequently, despite the relatively large size of the sample and the reasonably representative geographical and hospital-size distributions shown in the next two sections, the results might still be biased.

A simple check that provides an indication that a significant downward bias in the voluntarily submitted doses does not appear to have occurred is to compare the distribution of patient doses derived from routes 1 and 2 with those derived from route 3. In route 3, entrance surface doses (ESDs) were measured by NRPB's Patient Dosimetry Service (PDS) and the hospitals concerned have no knowledge of the doses prior to submission, so they cannot pre-select the data on this basis. For each of six common types of radiograph over 1000 ESD measurements were available made by thermoluminescent dosemeters (TLDs) of the PDS (via route 3) and over 1000 made by local hospital TLD services (via routes 1 or 2). For one of the six types of radiograph there was no significant difference between the mean ESD value measured by the PDS and that measured by local hospitals and for the other five radiographs the mean ESD values measured locally were significantly higher (>99.9% confidence as determined by Student's t test) than those measured by the PDS. This result suggests that concerns regarding high doses being withheld by data providers to the extent that they exert a downward bias on mean dose values, are probably unfounded.

2.2 Geographical distribution

We have continued the practice followed in the 1995 review[2] of using hospitals as the basic institutional unit rather than NHS Trusts. Figure 1 shows a map of the location of all the identifiable hospitals that supplied data for the 2000 review. At a first glance they appear to follow the population density distribution in the UK fairly closely apart from an apparent scarcity in SW England. A list of the participating hospitals, 263 in England, 18 in Northern Ireland, 26 in Scotland, and 64 in Wales is given in Appendix A. Throughout this report, clinics are included within the term 'hospitals'. The total number of hospitals (371) is almost identical to the total for the 1995 review (375) and is estimated to cover about 25% of all hospitals and clinics with diagnostic x-ray facilities in the UK.

In order to assess how representative the geographical distribution of the database is of NHS radiology practice, we have compared the percentage of the UK radiology workload, in each NHS region, with two parameters from the database. These two parameters are a) the number of NHS hospitals contributing to the database and b) the number of mean dose estimates for specific examinations or radiographs that relate to different rooms. The results are shown in Table 1. The NHS regions are those that were in operation at the beginning of 1996, the start of the period under review in this report (the regions were reorganised with effect from 1 January 1999). The radiology workload statistics for England for the financial year 1996-97 were taken from KH12 return data published by the Department of Health[9]. Similar workload statistics were derived for Scotland, Wales and Northern Ireland on the basis of their relative population sizes in comparison to England. It can be seen from Table 1 that the 'South & West' region is indeed somewhat under-represented in the database, as Figure 1 suggests. Other regions are somewhat over-represented such as West Midlands, Wales, and possibly Northern & Yorkshire (in terms of the number of rooms providing data, if not the number of hospitals). Requests to submit data were evenly distributed to medical physicists throughout the UK but, since this is a voluntary exercise, a uniform response could not be guaranteed. While it is in practice unavoidable that some regions will be under- or over-represented, it is at least apparent from Figure 1 and Table 1 that no region of the UK has been entirely neglected.

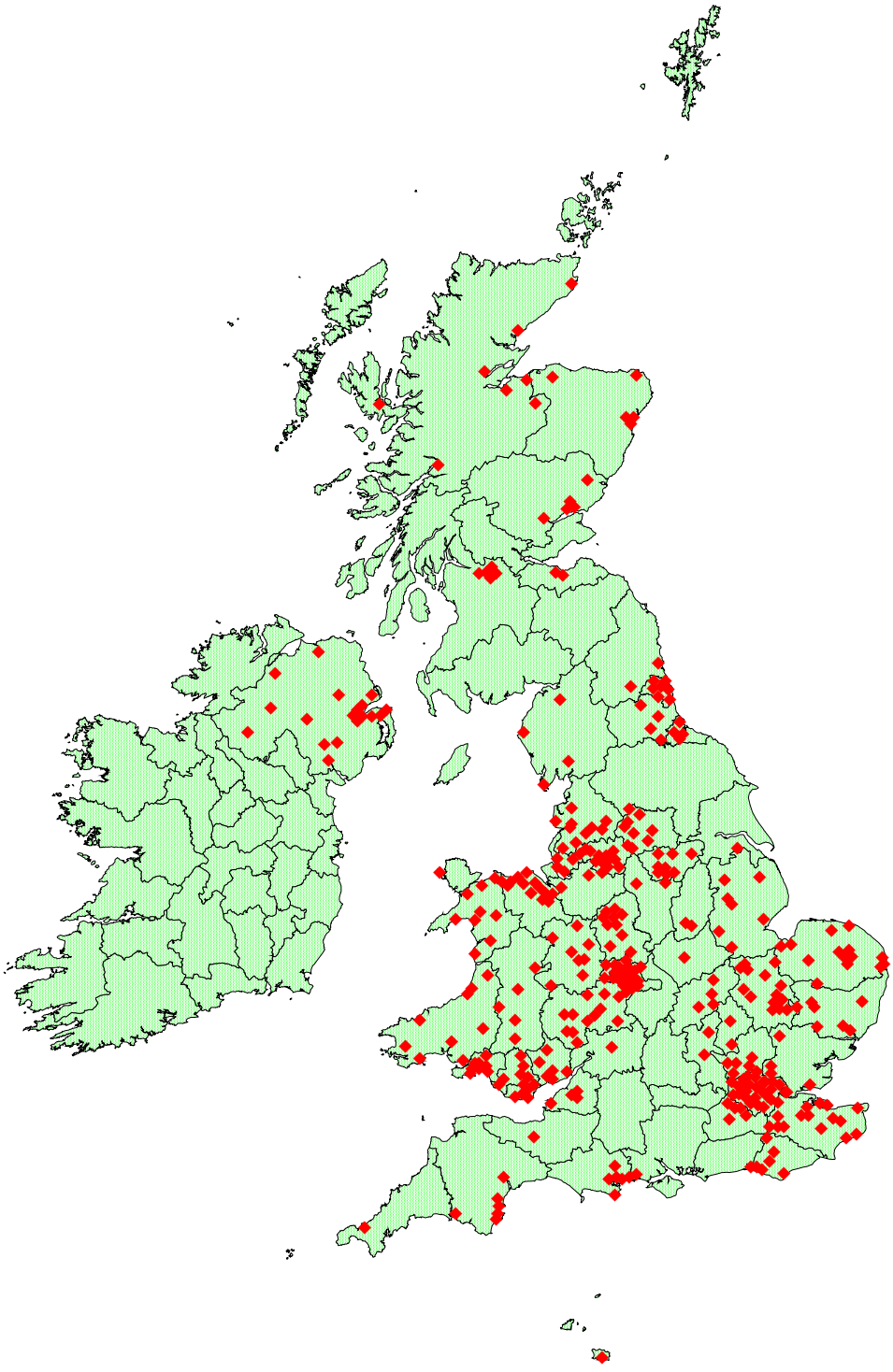

FIGURE 1 Geographical distribution of hospitals in sample

TABLE 1 Comparison of NHS radiology workload and database sample size on a regional basis

Region (as in 1996)	% of UK radiology workload (1996/97)	% of NHS hospitals in database	% of 'room mean dose estimates' in database
North Thames	13.1	6.7	8
North West	13.0	8.9	5
Northern and Yorkshire	11.4	9.6	37
South Thames	10.9	9.2	5
South and West	10.4	4.1	4
Trent	8.9	5.1	3
West Midlands	8.4	14.0	15
Anglia and Oxford	7.5	10.5	7
Scotland	8.6	6.4	3
Wales	4.9	20.1	10
Northern Ireland	2.9	5.4	3
	100	100	100

2.3 Distribution by size of hospital

It is important that the NPDD should contain data from a representative sample of hospitals of different sizes because medical physics support may be more readily available at larger hospitals and this could affect patient doses. A comparison with the national distribution of hospitals has therefore been made, using the number of beds as a convenient measure of hospital size. Table 2 shows the percentage of hospitals in the national database and in the UK (excluding psychiatric hospitals but including independent hospitals), as a function of the number of beds. Both sets of data have been taken from the Directory of Hospitals and Trusts 2000[10]. The two distributions are roughly similar, although there is a tendency to include more large hospitals and fewer small hospitals in the database than is truly representative. However, the smallest category (1-49 beds) has not been seriously neglected, despite the problems of obtaining sufficient dose measurements in a reasonable time in small x-ray departments.

TABLE 2 Percentage of hospitals in the UK and the National Patient Dose Database as a function of the number of beds

Number of beds per hospital	Percentage of hospitals	
	UK	National database
1-49	43.3	30.3
50-249	34.3	31.2
250-499	11.7	19.4
500-999	9.7	17.2
1000+	1.0	1.9

Source: reference 10

Out of the 371 hospitals and clinics from which patient dose measurements were obtained, 50 (or 13%) were in the independent sector. This is probably a slight over-representation of private hospitals, since they comprise about 10% of the numbers of all hospitals with radiology departments in the UK[9]. As independent hospitals have about 50 beds on average, while NHS hospitals average 190 beds, this over-representation of independent hospitals should be helping to counteract the relative lack of small hospitals in the database shown in Table 2.

3 DATA COLLECTED AND ANALYSED

3.1 Type and amount of data

Data were accepted in virtually any format, both on paper and as computer files. Most were sent by e-mail or on computer disc as a spreadsheet, which is the preferred format, since direct transfer into the database minimises the possibility of transcription errors. The forms shown in Appendix B indicate the data that are essential for the purposes of the National Patient Dose Database. These forms are revised versions of those printed in the National Protocol[1]. They have been updated to include additional information on digital image acquisition techniques (e.g. computed radiography and digital spot imaging). The forms can be freely photocopied for use in local radiology departments and were sent to all the medical physicists who were approached for data in July 2000.

During the period 1996-2000, data were received from 54 individuals working in medical physics or radiology departments throughout the UK, as listed in the Acknowledgements. This is an increase on the previous analysis[2], for which 37 people supplied data. A total of 28,000 ESD values for single radiographs,

13,000 DAP values for single radiographs, 140,000 DAP values for complete examinations and 128,000 records of the fluoroscopy time per examination were supplied between 1996 and 2000.

The number of ESD values per radiograph collected for this report has risen by 33% over the previous analysis[2]. About 35% of the ESD values were measured by TLDs supplied by the NRPB Patient Dosimetry Service, 45% were measured by TLDs supplied locally and 20% were calculated from the exposure factors used and their relationship to the output of the x-ray tube. The increased extent to which DAP meters are installed on x-ray sets, and the convenience of taking DAP measurements as compared with the processing of TLDs or the calculation of ESDs from exposure factors, has resulted in DAP values for single radiographs being included in the database in large numbers this time.

The number of DAP values per complete examination has increased more than four-fold over the number received for the 1995 review[2]. This is also due to the increased availability of DAP meters and has meant that DAP values have been provided for a much larger number of types of examination than previously. Information on the duration of fluoroscopy was included with over 90% of these DAP measurements. Although it is not so closely related to patient dose as the DAP, the fluoroscopy time is easily measured and provides a simple indication of the complexity of an examination that will be roughly proportional to the patient dose as long as fluoroscopy predominates over spot imaging. It can provide a useful alternative reference level for those situations where a DAP meter is not available and has already been suggested by the Department of Health as a suitable quantity in which to express DRLs for fluoroscopic examinations[8]. Consequently, we have included details of the distribution of this parameter in the results section and have provided reference levels in terms of fluoroscopy time in the discussion section.

A detailed breakdown of the numbers of patients, x-ray rooms and hospitals in the database for each type of radiograph or examination is given in section 4.

In the database, information is organised into 4 main types of file, related to:-

a) individual patients (including age, height, weight, and dose measurement)

b) groups of patients (for whom the mean dose and the number of patients is supplied, but not the dose for each patient)

c) the hospital (mainly the full address, but also whether NHS or independent)

d) the radiology room (mainly details of the x-ray imaging equipment used).

For the purposes of the database, a radiology room remains the same room only if it has the same radiological equipment in it. Thus, if a second set of measurements is carried out months later in nominally the same room, except that the equipment has been changed, then this is categorised in the database as a different room. Likewise, if it is not known whether the equipment remains the same, then this is also categorised as a different room.

Table 3 shows the amount of data provided on some of the factors that are most likely to affect patient dose. This is expressed as either the percentage of dose measurements of each type or the percentage of rooms for which information on the specified factor was supplied. Where the information was merely a 'yes' or 'no' answer, the numbers in brackets show the positive answers expressed as a percentage of those that responded. Thus, 6% of rooms provided information on whether or not the antiscatter grid had a carbon fibre cover; of these rooms, 20% did have one. The key parameters for individual patients (weight, height and age) were supplied more frequently than in our previous review[2]. About 35% of the dose measurements for individual radiographs were accompanied by a film-screen speed rating, which is a lower response than the 58% seen previously[2]. This might be because more radiographic examinations were conducted using computed radiography in the latest review.

TABLE 3 Data provision on factors likely to affect patient dose

Factor	Percentage of rooms		
Total filtration	25		
Grid ratio	7		
Grid strips/cm	7		
Carbon fibre grid cover Yes/No	6 (20)		
Aluminium equivalence of couch	5		
	Percentage of dose measurements		
	DAP/exam.	ESD/radiog.	DAP/radiog.
Patient weight	72	74	47
Patient height	70	53	37
Patient age	84	41	53
Radiographic kV	-	90	92
FFD/FSD	-	80	35
AEC used Yes/No	-	65 (38)	50 (42)
Fluoroscopic kV	1.6	-	-
Fluoroscopy time	90	-	-
Number of exposures	70	-	-
Film-screen speed	6	34	36

FFD/FSD = focus-film distance/focus-skin distance

AEC = Automatic exposure control

3.2 Quality assurance of data

The data supplied were initially scrutinised by one of the authors (DH) and data providers were often contacted to verify details. Data were entered into the database by one person and then checked independently by a second person. A

statistical programme was run on each set of data that produced the mean, standard deviation, sample size, and minimum and maximum for several key parameters. These parameters included the dose, patient age, patient weight, applied potential, filtration, and exposure setting (mAs) for each radiograph or examination. Extreme values were investigated and any errors discovered in the data entered were corrected. The database was password-protected such that access to the programs or the data files in anything but a read-only manner was restricted to the one staff member responsible for developing the database software. Analysis programs were checked against manual calculations with dummy datasets and the results of new calculations were compared to earlier ones to verify that the expected changes had occurred.

The National Protocol[1] provides guidance on the calibration and use of TLD systems for measuring ESD and of DAP meters, so that patient dose measurements can be made with sufficient accuracy. It was assumed that all data providers were following this guidance and that the doses submitted to the NPDD were as reliable as the guidance predicts. Many data-providers included calibration data with their dose measurements, which suggested that the guidance in the National Protocol was being followed correctly and increased our confidence in the above assumption.

An investigation by Crawley et al[11] of the calibration of 41 DAP meters over a five-year interval in the Oxford area revealed that undercouch tube configurations were more frequently found to be miscalibrated than overcouch configurations. It was suggested that this might be due to service engineers re-calibrating the DAP meter to the factory standard (i.e. without taking account of the couch lying between the DAP meter and the patient) leading to errors of the order of 25% in the DAP meter readings. It was therefore recommended that managers of radiological equipment agree with the relevant manufacturers that service personnel do not adjust DAP meters unless specifically requested by the appropriate staff. Hospital personnel providing data to the NPDD in the future are asked to take note of this recommendation.

3.3 Selection of data for analysis

3.3.1 Adult patients

The national protocol[1] recommends that measurements should be made on at least ten adults when obtaining an estimate of the typical dose to an average adult patient for comparison of local performance with national reference doses. Since patients' doses are dependent on patient size, the protocol also indicated that the mean weight of the sample should lie in the range 65 to 75 kg for the mean dose to be indicative of the typical dose to an average (70kg) patient. To help achieve this, the protocol advocated excluding those patients weighing less than 50 kg or more than 90 kg. Not all data-providers followed these suggestions when submitting data to the National Patient Dose Database.

For the 1995 analysis[2] of the National Patient Dose Database, it was decided to select doses for analysis only where individual adult patients were between 50 and 90 kg, and where the mean weight of a sample of patients in a room was between 65 and 75 kg. Additionally, there had to be at least two remaining patient dose measurements for a specific radiograph or examination in a room for that room to be included in the analysis. While this selection procedure ensured that the resulting mean doses for a room were representative of patients of average weight, there was some concern that this was not making maximum use of the data provided. By selecting in this way, the number of dose measurements on individual patients was reduced by 30% for all radiographs and examinations with reference doses. The number of radiology rooms was likewise reduced by 45%. However, key parameters of the room mean dose distribution were not markedly affected by selecting the data in this way. The mean, median and third quartiles for this distribution were very similar to those for the distribution when all adult patients were selected. The percentage differences between these parameters for the two datasets for all the projections and examinations with reference doses never exceeded $\pm$24%, and the average was +0.1%. This difference is very small.

Therefore, for this 2000 review, we decided to examine a range of selection procedures and see how much each one reduced the sample sizes, and whether they significantly affected key parameters of the room mean dose distribution. Nineteen selection procedures were analysed, including that of taking all the data, and their results were compared. These 19 selection procedures are listed in Table 4.

TABLE 4 Nineteen selection procedures for which effects were compared

1) All data
2) All adults (patient age ≥ 16 years)
3) Adults; 50-90 kg for individuals
4) Adults; mean weight for room sample 65-75 kg
5) Adults; minimum 2 patients/room
6) Adults; minimum 5 patients/room
7) Adults; minimum 10 patients/room
8) Adults; 50-90 kg for individuals, mean weight 65-75 kg
9) Adults; 50-90 kg for individuals, minimum 2 patients/room
10) Adults; 50-90 kg for individuals, minimum 5 patients/room
11) Adults; 50-90 kg for individuals, minimum 10 patients/room
12) Adults; mean 65-75 kg, minimum 2 patients/room
13) Adults; mean 65-75 kg, minimum 5 patients/room
14) Adults; mean 65-75 kg, minimum 10 patients/room
15) Adults; 50-90 kg for individuals, mean 65-75 kg, minimum 2 patients/room (as in 1995 review)
16) Adults; 50-90 kg for individuals, mean 65-75 kg, minimum 5 patients/room
17) Adults; 50-90 kg for individuals, mean 65-75 kg, minimum 10 patients/room
18) Adults; mean 65-75 kg OR if weight unknown, minimum 5 patients/room
19) Adults; mean 65-75 kg OR if weight unknown, minimum 10 patients/room

The results of applying the 19 selection procedures to examinations and radiographs with large sample sizes are indicated in Tables 5, 6 and 7, which show data from each of the 3 types of dose measurement in the database (i.e. DAP/examination, ESD/radiograph, DAP/radiograph), respectively. The impact of the selection procedures on the numbers of hospitals, rooms and patient dose measurements left in the sample is shown, together with key parameters of the room mean dose distribution.

Excluding patients of less than 50 kg or more than 90 kg (selection procedure 3) clearly much reduces the data available for analysis compared with including all adults (selection procedure 2). Over the whole database, the number of measurements is reduced by 37%. Most of this reduction is not actually due to patients being outside the stated range of weights, but because the patient weight is unknown for 30% of dose measurements and therefore these data cannot be included. A similar consideration applies to restricting the mean weight of the patients in a room to 65-75 kg (selection procedure 4). This selection procedure reduces the total number of dose measurements in the database by 36%. Only one-sixth of this reduction is due to the mean weight being outside the range, all the rest is due to the patient weight being unknown. Many of the other selection criteria are equally severe in their reduction of the sample size. It is however also apparent that none of the selection procedures make much difference to the mean or third quartile values of the room mean dose distributions. As a *rounded* third quartile has been used in the past to set national reference doses, slight variations in the third quartile values are of no significance.

It is necessary to ensure that the data presented in this report are representative of a typical adult. In our previous report we used selection procedure 15 to achieve this, but Tables 5 to 7 show that, as before, this almost halves the available data. Using only selection procedure 4 would ensure that each room's data is near to that for a typical weight of 70 kg, but would reduce the data by around 30%. We therefore included in the list of selection procedures two options (18 and 19) that selected data if either the mean patient weight in a room was 65-75 kg or, if the patient weights were not provided, the number of patients measured in a room was above a specified minimum. If at least 5 or 10 patients are being measured, then it is unlikely that they would all be either over or under weight. So that even though the patient weight is not known in these cases, it is unlikely that the mean will be very far from 70 kg (especially in the case of 10 patients per room). As mentioned in the paragraph above, only 6% of all rooms in the database had a mean weight outside 65-75 kg, regardless of the number of patients whose doses were measured. These options (selection procedures 18 and 19) do not reduce the dataset as drastically as selection procedure 4. Even the more stringent selection procedure (procedure 19) retains between 68% to 93% of the data in the 'all adults' selection (procedure 2). Moreover, differences in the third quartile values between selection procedures 15 (as used in 1995 review) and 19 are small, ranging from 0-14 % with an average of only about 2%. It was therefore decided to use selection procedure 19 for the main analysis of results for this report.

TABLE 5 Effects of selection procedures for DAP/examination (Gycm^2)

	Selection Procedure	1 All data	2 Adults	3 50-90kg	4 65-75kg	5 2pts/rm	6 5pts/rm	7 10pts/rm	8 3+4	9 3+5	10 3+6	11 3+7	12 4+5	13 4+6	14 4+7	15 3+4+5	16 3+4+6	17 3+4+7	18 4 or 6	19 4 or 7
All exams	Hospitals	131	129	108	93	128	125	115	94	107	106	101	93	92	87	94	93	88	123	118
	Rooms	396	390	339	307	382	365	328	310	330	317	284	303	291	263	302	290	260	368	362
	Measurements	142301	132917	91315	87482	131812	128664	124166	75156	90363	87628	83847	87259	86364	84329	74864	73567	71203	111667	111150
Ba Enema	Hospitals	94	93	80	67	92	87	82	67	79	75	72	67	64	61	67	64	61	88	86
	Rooms	230	222	202	168	216	199	179	173	195	180	163	167	160	149	171	163	150	194	191
	Measurements	50628	50404	36394	41777	50398	50352	50206	33325	36387	36349	36234	41796	41757	41677	33323	33302	33214	49986	49967
	Mean DAP	22.6	23.5	22.7	23.1	23.8	24.0	24.1	22.6	23.0	23.5	23.5	23.2	23.5	23.5	22.7	23.0	22.9	23.5	23.5
	Max/Min	854	276	298	29	276	29	29	31	298	25	25	20	20	20	25	25	25	29	29
	3rd Quartile	30.9	31.3	29.8	30.7	31.7	31.7	32.1	29.8	30.0	30.4	30.4	30.8	31.3	31.7	30.0	30.0	30.0	31.2	31.3
Ba Meal	Hospitals	84	80	65	53	79	70	60	55	65	60	50	53	51	43	55	53	43	70	68
	Rooms	214	205	174	129	189	163	134	137	162	142	108	126	118	102	132	122	98	151	148
	Measurements	9588	8059	5760	5939	8043	7965	7752	4791	5748	5686	5446	5936	5911	5789	4786	4757	4581	7709	7689
	Mean DAP	10.7	11.1	10.7	10.2	10.7	10.5	10.5	10.2	10.6	10.4	10.0	10.3	10.3	10.4	10.2	10.1	9.9	10.3	10.3
	Max/Min	4400	331	39	37	66	16	16	35	18	18	15	16	16	16	16	15	15	37	37
	3rd Quartile	13.0	13.6	13.2	12.9	13.4	13.3	13.4	12.9	12.9	12.9	12.6	12.9	13.2	13.3	12.8	12.7	12.5	13.2	13.0
Ba Swallow	Hospitals	57	55	42	32	55	49	45	32	42	39	34	32	31	26	32	29	25	49	49
	Rooms	193	184	160	99	174	153	134	112	151	131	107	98	92	83	109	99	84	124	124
	Measurements	12593	11777	7871	8954	11769	11706	11568	6953	7862	7802	7635	8953	8933	8864	6950	6916	6810	10439	10439
	Mean DAP	7.3	8.0	7.7	7.6	7.9	8.0	7.9	8.0	7.6	7.6	7.2	7.6	7.7	7.4	8.0	7.9	7.2	8.0	8.0
	Max/Min	555	283	101	31	185	47	27	32	49	49	10	24	24	24	22	22	9	31	31
	3rd Quartile	9.4	10.4	10.2	9.5	10.4	10.1	10.0	10.3	9.8	10.2	9.0	9.5	9.7	8.8	10.3	10.3	8.8	10.2	10.2
IVU	Hospitals	48	47	43	29	39	32	27	29	34	29	24	27	22	19	27	24	20	34	34
	Rooms	91	87	72	41	53	41	32	46	46	38	28	34	29	22	37	32	23	46	46
	Measurements	1834	1807	1321	845	1773	1736	1670	874	1295	1271	1198	838	822	772	865	850	784	1412	1412
	Mean DAP	12.5	13.7	13.1	14.0	14.6	15.1	16.4	14.0	13.7	14.5	15.5	11.6	11.4	11.9	11.6	11.7	11.5	14.5	14.5
	Max/Min	1103	235	114	55	56	27	27	55	61	29	29	9	9	9	9	9	9	55	55
	3rd Quartile	16.5	17.1	16.0	15.5	17.2	17.2	19.5	16.2	16.1	16.1	16.7	13.9	13.4	13.9	14.2	14.1	13.5	16.2	16.2

TABLE 6 Effects of selection procedures for ESD/radiograph (mGy)

Selection Procedure		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
		All data	Adults	50-90kg	65-75kg	2pts/rm	5pts/rm	10pts/rm	3+4	3+5	3+6	3+7	4+5	4+6	4+7	3+4+5	3+4+6	3+4+7	4 or 6	4 or 7
All radiographs	Hospitals	287	281	268	211	276	260	226	225	264	251	200	209	197	168	222	211	164	253	249
	Rooms	1621	1591	1511	1010	1496	1180	656	1112	1419	1056	449	959	765	441	1065	818	354	1144	1106
	Measurements	27971	24782	21791	14959	23632	20772	13362	15377	21177	18276	10054	14788	13502	9335	15191	13645	8029	18283	16937
Abdomen AP	Hospitals	177	171	161	93	154	126	74	103	145	117	57	91	74	50	100	84	47	116	104
	Rooms	598	583	541	262	489	330	142	311	459	287	83	246	180	85	292	205	67	304	280
	Measurements	4018	3587	3001	1854	3493	3019	1685	2051	2919	2395	961	1838	1633	958	2032	1753	776	2315	2144
	Mean ESD	4.49	4.62	4.48	4.66	4.73	4.90	5.03	4.56	4.53	4.69	5.11	4.72	4.79	5.01	4.62	4.70	5.04	4.58	4.66
	Max/Min	144	56	56	52	53	53	53	54	54	53	53	53	53	53	54	54	54	53	53
	3rd Quartile	5.57	5.62	5.49	5.57	5.62	5.82	5.91	5.55	5.49	5.73	6.17	5.58	5.71	5.92	5.57	5.66	6.04	5.53	5.55
Chest PA	Hospitals	220	213	203	157	208	199	167	161	201	193	151	157	151	126	160	155	121	192	190
	Rooms	588	574	544	357	522	447	325	382	500	428	263	346	310	231	368	330	207	431	415
	Measurements	6534	6161	5547	4427	6109	5891	4988	4483	5503	5295	4082	4416	4305	3722	4469	4351	3439	5256	5133
	Mean ESD	0.15	0.15	0.14	0.15	0.15	0.15	0.14	0.15	0.15	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.14	0.15	0.15
	Max/Min	160	160	105	123	160	123	123	105	105	105	76	123	123	123	105	105	76	123	123
	3rd Quartile	0.18	0.18	0.18	0.19	0.18	0.17	0.17	0.18	0.18	0.17	0.16	0.19	0.18	0.17	0.18	0.17	0.17	0.18	0.18
L spine AP	Hospitals	176	173	167	116	162	149	86	126	159	144	67	112	105	65	121	111	56	140	126
	Rooms	511	503	481	273	422	298	129	292	415	275	96	251	196	97	267	198	77	317	289
	Measurements	3086	3042	2838	1977	2961	2600	1473	1997	2772	2365	1115	1955	1794	1128	1972	1762	912	2355	2151
	Mean ESD	5.04	5.10	4.95	5.07	5.17	5.29	5.13	5.03	4.95	5.15	5.05	5.06	5.29	5.09	5.04	5.34	5.12	5.02	5.03
	Max/Min	760	215	215	215	215	215	44	215	215	215	44	215	215	44	215	215	44	215	215
	3rd Quartile	5.99	6.05	5.91	5.82	6.06	6.41	6.55	5.91	5.88	6.28	6.57	5.81	6.09	6.11	5.87	6.28	6.56	5.91	5.82

TABLE 7 Effects of selection procedures for DAP/radiograph (Gycm^2)

Selection Procedure		1 All data	2 Adults	3 50-90kg	4 65-75kg	5 2pts/rm	6 5pts/rm	7 10pts/rm	8 3+4	9 3+5	10 3+6	11 3+7	12 4+5	13 4+6	14 4+7	15 3+4+5	16 3+4+6	17 3+4+7	18 4 or 6	19 4 or 7
All radiographs	Hospitals	96	92	78	73	87	84	74	74	77	73	63	71	67	61	72	70	60	83	81
	Rooms	254	229	199	182	219	196	151	186	193	170	123	177	158	121	181	163	117	205	201
	Measurements	13015	10497	5529	4961	10334	9698	7842	4987	5435	4998	3429	4930	4637	3398	4956	4648	3238	9499	9076
Abdomen AP	Hospitals	66	60	49	39	55	49	30	41	46	40	23	37	34	22	39	36	22	48	45
	Rooms	130	118	94	71	107	90	47	75	86	70	31	67	60	31	71	63	30	90	85
	Measurements	1525	1161	757	651	1150	1101	774	674	749	703	404	647	626	403	670	646	393	1034	1000
	Mean DAP	2.32	2.52	2.40	2.33	2.50	2.43	2.65	2.32	2.33	2.24	2.40	2.21	2.22	2.35	2.20	2.23	2.38	2.48	2.49
	Max/Min	109	77	12	11	12	8	6	10	12	7	4	7	7	4	7	7	4	10	10
	3rd Quartile	3.01	3.06	2.92	2.79	3.04	3.02	3.31	2.79	2.89	2.77	3.15	2.72	2.69	3.15	2.72	2.72	3.20	3.05	3.07
Chest PA	Hospitals	69	63	55	50	61	60	53	49	54	53	43	49	47	41	48	47	40	57	57
	Rooms	140	128	107	94	120	110	89	96	102	93	67	91	84	65	93	86	64	111	111
	Measurements	3279	2959	1175	1092	2951	2920	2761	1098	1170	1142	945	1089	1066	922	1095	1072	905	2833	2833
	Mean DAP	0.09	0.10	0.09	0.09	0.10	0.10	0.10	0.09	0.10	0.10	0.10	0.09	0.09	0.10	0.09	0.09	0.10	0.10	0.10
	Max/Min	184	184	14	9	14	14	9	9	14	14	9	9	9	9	9	9	9	9	9
	3rd Quartile	0.11	0.12	0.11	0.11	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.11	0.11	0.12	0.12
L spine AP	Hospitals	63	59	52	44	56	50	33	46	51	45	23	43	40	26	45	41	22	49	49
	Rooms	118	112	93	80	104	83	47	82	89	71	33	79	66	36	81	67	32	92	89
	Measurements	1178	1156	775	728	1148	1085	815	731	771	718	427	727	688	459	730	688	417	1084	1064
	Mean DAP	1.39	1.44	1.30	1.29	1.42	1.40	1.38	1.27	1.30	1.31	1.26	1.30	1.28	1.23	1.28	1.27	1.25	1.36	1.36
	Max/Min	109	109	53	53	25	11	11	53	11	9	7	9	9	7	11	9	7	67	67
	3rd Quartile	1.62	1.70	1.59	1.54	1.63	1.64	1.62	1.52	1.57	1.61	1.59	1.55	1.56	1.58	1.53	1.55	1.60	1.62	1.62

3.3.2 Paediatric patients

In this review, as in the previous report[2], children have been defined as aged up to and including fifteen years old. Thus sixteen year olds and above are all defined as adults. About 8% of all the dose measurements in the database relate to children.

NRPB has previously developed a method for adjusting doses measured on children to derive the dose that would have been given to the nearest standard-sized child[12]. Five standard sizes of children were chosen representing 0, 1, 5, 10 and 15 year olds. It was shown that it was feasible to establish reference doses for this set of standard-sized children, by taking the third quartile of the distribution of normalised doses at each age from several hospitals. Other hospitals could then compare their local performance with these reference doses. The normalisation of doses was based on adjusting for the thickness of the body part being x-rayed. This could either be measured directly or, if more convenient, could be calculated from the height and weight of the patient. These methods have been applied to the limited amount of data on paediatric patients in the NPDD.

Using this method of adjusting doses according to patient size, there was no need to select samples of paediatric patients according to their mean weight or to insist on a minimum number of 5 or 10 patients per room, as was the case for adult patients.

4 RESULTS

4.1 ESD per radiograph

For each type of radiograph, having used selection procedure 19 as described in section 3.3, a mean ESD value was calculated for each set of dose measurements in one room (where a room is defined as in section 3.1). Table 8 shows the key parameters of the mean ESD per room distribution for all those radiographs that had data from at least 10 hospitals, 20 rooms and 100 patients. Those radiographs which had an even bigger sample, from at least 20 hospitals, 40 rooms and 200 patients, are placed in the top part of this table. The key parameters of the dose distribution shown in the table are the mean, minimum, maximum, first quartile, median and third quartile values for the room means. Thus the column headed 'Mean' contains the mean values of the room mean ESDs for each type of radiograph.

Table 9 shows the mean patient characteristics and exposure parameters for the same radiographs listed in Table 8, using information drawn from the selected dataset.

TABLE 8 Radiographs: summary of data on mean entrance surface dose per room for selected dataset

Radiograph	No.of hosps	No. of Rooms	No. of patients	Room mean ESD distribution (mGy)					
				Mean	Min.	Max.	1st quart.	Median	3rd quart.
	>20	>40	>200						
Abdomen AP	104	280	2144	4.7	0.28	14.6	3.3	4.1	5.6
Chest PA	190	415	5133	0.15	0.01	1.5	0.08	0.12	0.18
L Spine AP	126	289	2151	5.0	0.32	68.4	3.2	4.3	5.8
L Spine LAT	160	362	2690	11.7	0.52	147	7.4	10.1	13.8
L Spine LSJ	74	107	660	24.3	1.1	179	14.9	20.8	26.2
Pelvis AP	144	306	2220	3.6	0.24	15.4	2.4	3.2	4.2
Skull AP/PA	26	48	329	2.3	0.38	5.5	1.4	1.9	2.8
T Spine AP	29	47	230	2.9	0.13	8.7	2.1	2.4	3.4
T Spine LAT	29	50	241	8.0	0.27	29.1	4.3	6.7	10.4
	>10	>20	>100						
Chest LAT	22	28	112	0.85	0.14	3.5	0.31	0.51	0.99
Chest AP	17	25	236	0.14	0.06	0.28	0.11	0.14	0.16
Skull LAT	32	38	243	1.2	0.09	2.8	0.7	1.1	1.6

TABLE 9 Radiographs (entrance surface dose data): mean patient characteristics and exposure parameters for selected dataset

Radiograph	Patient age (years)	Patient weight (kg)	Tube potential (kV)	Total Filtration (mm Al)	Exposure setting (mA s)
Abdomen AP	52(16-92)	71(32-121)	74(53-125)	2.6(2.5-3.5)	46(2-640)
Chest PA	57(16-99)	70(32-126)	85(50-150)	2.8(2.5-4.3)	5(0.5-69)
L Spine AP	52(16-96)	70(35-121)	77(55-110)	2.7(2.5-4.0)	42(5-400)
L Spine LAT	52(16-92)	70(35-115)	88(65-125)	2.7(2.5-4.0)	72(1-500)
L Spine LSJ	54(16-92)	70(35-108)	95(72-125)	2.7(2.5-3.5)	110(11-485)
Pelvis AP	61(16-96)	70(35-118)	74(55-117)	2.8(2.5-4.0)	35(2.4-400)
Skull AP/PA	45(16-91)	70(48-105)	72(55-85)	2.5(2.5-3.3)	30(6-80)
T Spine AP	53(19-87)	70(35-105)	76(53-105)	2.7(2.5-3.3)	31(4-219)
T Spine LAT	52(19-87)	71(35-105)	73(50-109)	2.7(2.5-3.0)	66(3-400)
Chest LAT	63(25-88)	70(51-90)	98(72-141)	2.6(2.5-3.0)	15(3-64)
Chest AP	69(18-87)	70(41-102)	76(60-95)	2.8(2.5-3.0)	3(1.2-9)
Skull LAT	44(16-90)	69(46-134)	66(54-90)	2.5(2.5-3.3)	19(4-50)

Note: the range from minimum to maximum for individual patients is given in brackets.

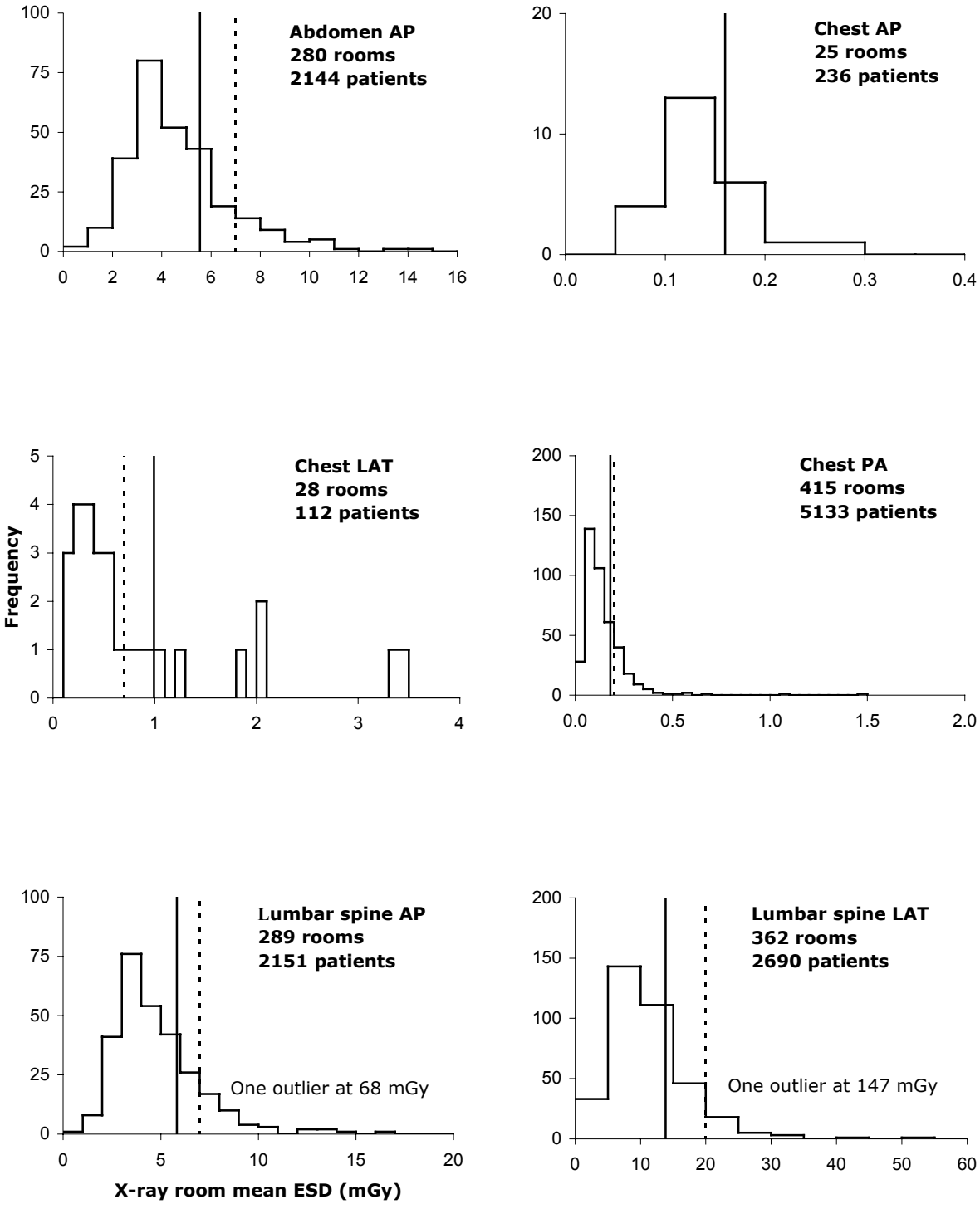

FIGURE 2 Distribution of x-ray room mean entrance surface dose

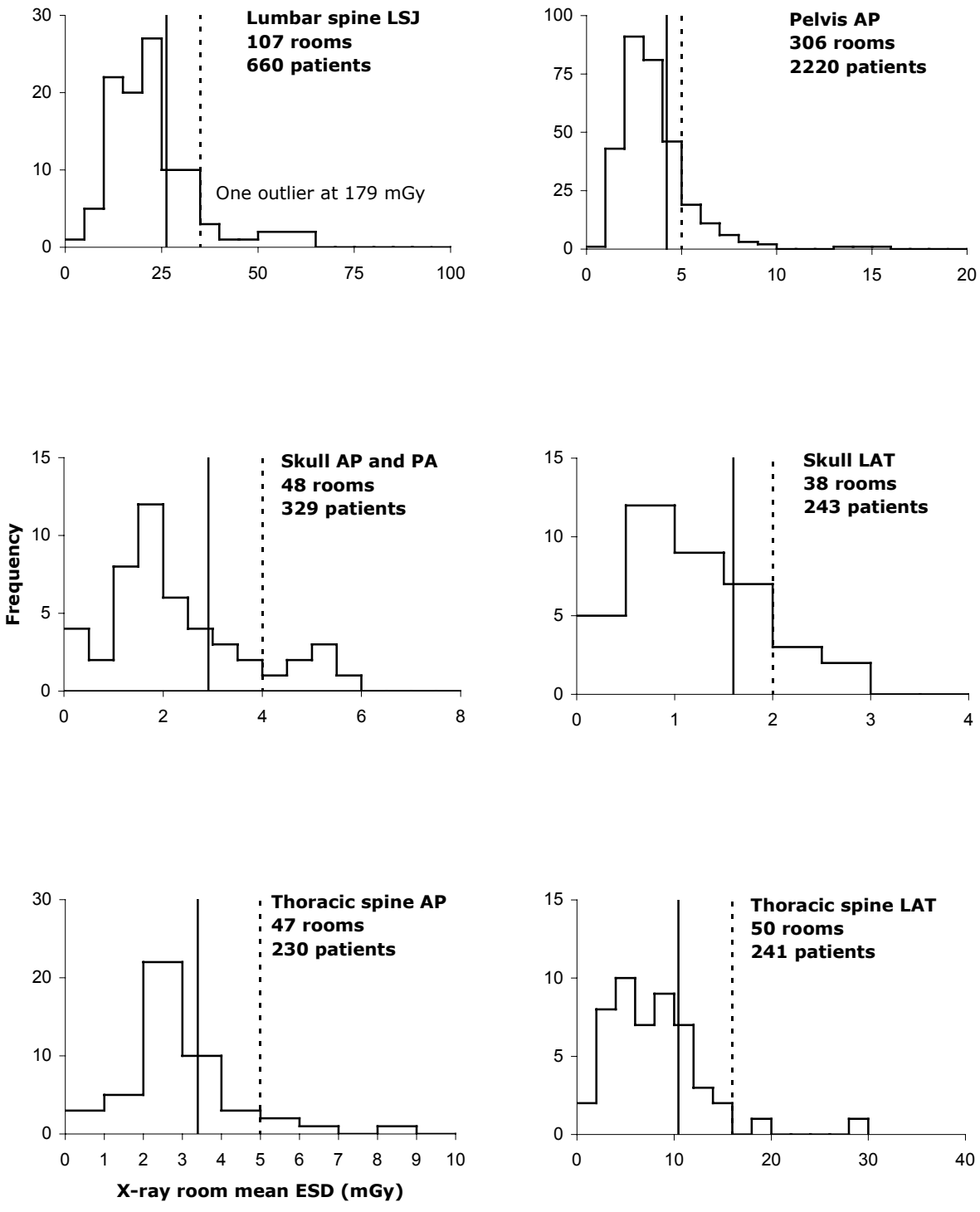

FIGURE 2 (continued)

Figure 2 shows histograms of x-ray room mean ESD values for the 12 types of radiograph in Table 8. These histograms are again drawn from the selected dataset. The 'Frequency' indicated on the vertical axes in Figure 2 is the number of x-ray rooms in each dose band of the histogram. The total number of x-ray rooms and the total number of patients or dose measurements contributing to the histogram of room mean values are indicated for each type of radiograph. A solid vertical line indicates the third quartile value of the current data and a dotted vertical line indicates the third quartile value from the 1995 review. The current third quartile values lie below the 1995 values for all but one type of radiograph (chest lateral), indicating that there has been a general reduction in doses in the period since the last review.

4.2 DAP per radiograph

For each type of radiograph, having used selection procedure 19 as described in section 3.3, a mean DAP value was calculated for each set of dose measurements in one room (where a room is defined as in section 3.1). Table 10 shows the key parameters of the mean DAP per room distribution for the six types of radiograph that had data from at least 10 hospitals, 20 rooms and 100 patients. It can be seen that these six types actually had an even bigger sample, from at least 20 hospitals, 40 rooms and 200 patients. The key parameters of the dose distribution shown in the table are the mean, minimum, maximum, first quartile, median and third quartile values for the room means, as in Table 8.

TABLE 10 Radiographs: summary of data on mean dose-area product per room for selected dataset

Radiograph	No. of hosps.	No. of rooms	No. of patients	Room mean DAP distribution ($Gycm^2$)					
				Mean	Min.	Max.	1st quart.	Median	3rd quart.
Abdomen AP	45	85	1000	2.5	0.8	8.2	1.6	2.2	3.1
Chest PA	57	111	2833	0.10	0.03	0.24	0.07	0.09	0.12
L Spine AP	49	89	1064	1.4	0.06	3.7	1.0	1.3	1.6
L Spine LAT	52	91	1088	2.3	0.09	5.8	1.5	2.1	2.8
L Spine LSJ	31	43	266	2.4	0.5	6.7	1.4	1.8	2.9
Pelvis AP	58	100	1203	2.2	0.5	7.3	1.6	2.0	2.7

Table 11 shows the mean patient characteristics and exposure parameters for the same radiographs listed in Table 10, using information drawn from the selected dataset.

TABLE 11 Radiographs (dose-area product data): mean patient characteristics and exposure parameters for selected dataset

Radiograph	Patient age (years)	Patient weight (kg)	Tube potential (kV)	Total filtration (mm Al)	Exposure setting (mAs)
Abdomen AP	52(16-89)	70(32-103)	73(49-156)	2.9(2.5-3.6)	54(4-928)
Chest PA	58(17-93)	70(32-108)	83(50-150)	2.9(2.5-3.6)	5(0.1-160)
L Spine AP	52(17-94)	70(45-102)	76(55-100)	2.7(2.5-3.5)	50(2-400)
L Spine LAT	52(17-94)	70(45-102)	87(53-120)	2.7(2.5-3.5)	64(2-400)
L Spine LSJ	53(16-90)	70(51-90)	95(70-125)	2.7(2.5-3.4)	101(5-485)
Pelvis AP	60(19-94)	70(42-102)	74(54-96)	2.8(2.5-3.7)	46(2-480)

Note: the range from minimum to maximum for individual patients is given in brackets.

Figure 3 shows the histograms of x-ray room mean DAP values for all the radiographs in Table 10. These histograms are again drawn from the selected dataset and the same information is given for each histogram as in Figure 2. A solid vertical line indicates the third quartile value on each histogram.

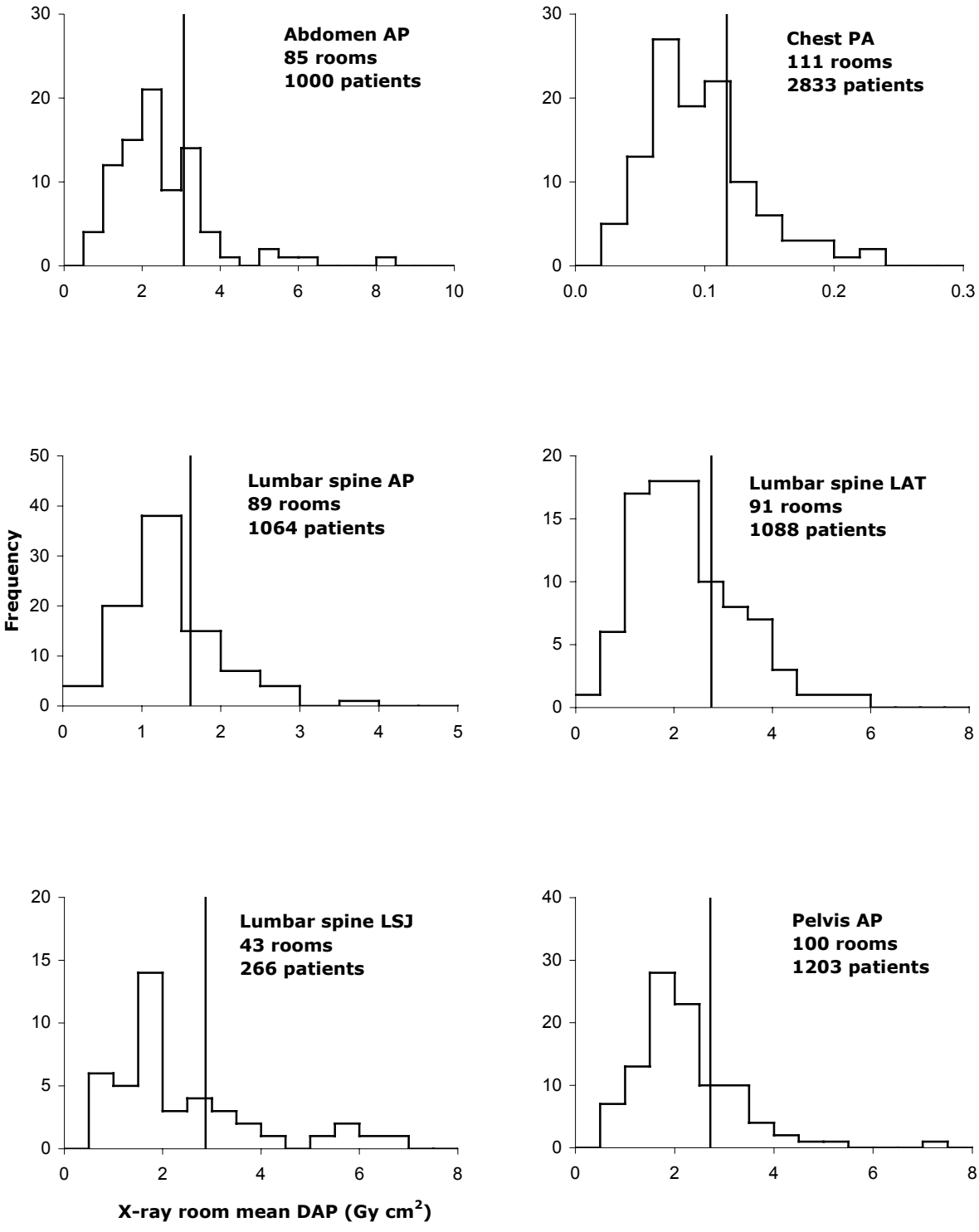

FIGURE 3 Distribution of x-ray room mean dose-area product per radiograph

4.3 DAP per examination

For each type of examination, having used selection procedure 19 as described in section 3.3, a mean DAP value was calculated for each set of dose measurements in one room (where a room is defined as in section 3.1). Table 12 shows the key parameters of the mean DAP per room distribution and has a similar layout to Table 8, except that there is an additional section at the bottom. This section shows a few examinations that did not quite reach all the minimum criteria of 10 hospitals, 20 rooms and 100 patients. They have been included because they very nearly reach the above criteria or because they contain data for large numbers of patients. Some of them are also relatively high-dose examinations often performed by clinicians who are not specifically trained in radiology and for whom reference doses might be particularly helpful.

One such examination is coronary angiography, but it was found that for 12 of the 17 rooms that provided data on ≥10 patients, the mean patient weight was higher than the 65-75 kg range required by selection procedure 19. For the other 5 rooms no information on patient weight was provided. The mean weight of all the patients undergoing coronary angiography was in fact 78 kg, significantly higher than the 70 kg that is typical for all other examinations (see Table 13). This result is not surprising, since it is well known that many patients suffering from heart disease tend to be overweight. The required range for the mean patient weight in a room for coronary angiography was consequently increased to 75-85 kg or, if the weight was unknown, a minimum of 10 patients per room was required.

Most of the examinations listed in Table 12 are clearly specified and can be seen to involve a diagnostic or an interventional study of a specific anatomical area in the body. It should be noted, however, that the examination designated 'ERCP' (endoscopic retrograde cholangiopancreatography) can be a diagnostic and/or an interventional procedure, and for most of the data submitted this distinction was not made clear. The 'ERCP' DAP values given in the Table consequently apply to an unknown mixture of diagnostic and/or interventional ERCP procedures. Also, the examination designated 'biliary intervention' may include some 'biliary drainage' procedures, which are also listed separately in this table, as well as other interventional biliary procedures, such as stone removal.

Table 13 shows the mean patient characteristics and exposure parameters for the examinations listed in Table 12, using information drawn from the selected dataset. The final column of the table shows the rounded mean number of film-screen images that were taken per examination, calculated only for those patients who had such images. For some of these examinations, such as coronary angiograms, oesophageal dilation and pacemaker insertion, there were very few patients for whom any film-screen radiographs were taken. Therefore the mean number of film-screen images listed here is not necessarily a typical value for all examinations of that type.

Figure 4 shows histograms of x-ray room mean DAP values for the nine examinations in the upper part of Table 12. These histograms are again drawn

from the selected dataset and the same information is given for each histogram as in Figure 2. A solid vertical line indicates the third quartile value of the current data, and a dotted vertical line indicates the third quartile value from the 1995 review for the three examinations barium enema, barium meal and IVU (intravenous urography). For these examinations, the third quartile values in the current database are all lower than those seen in the 1995 review.

TABLE 12 Complete examinations: summary of data on mean dose-area product per room for selected dataset

Examination	No. of hosps.	No. of rooms	No. of patients	Room mean DAP distribution (Gycm^2)					
				Mean	Min.	Max.	1ST quart.	Median	3RD quart.
	>20	>40	>200						
Barium follow through	28	60	1701	10.7	1.7	34.9	4.7	8.5	13.7
Barium enema	86	191	49967	23.5	2.9	84.5	14.9	22.4	31.3
Barium meal	68	148	7689	10.3	0.8	30.4	6.6	9.1	13.0
Barium swallow	49	124	10439	8.0	1.3	40.4	4.9	6.6	10.2
ERCP	28	57	5060	15.5	2.0	37.0	10.7	14.1	19.0
Femoral angiogram	23	65	6089	25.9	1.1	96.2	14.5	19.8	32.5
Hysterosalpingogram	22	49	1338	3.5	0.4	15.7	1.8	3.0	4.3
IVU	34	46	1412	14.5	1.6	90.3	6.8	12.2	16.2
Venogram (leg)	32	56	1157	4.5	0.4	24.2	2.1	3.0	5.0
	>10	>20	>100						
Biliary drainage	10	21	202	34.1	7.1	93.2	12.2	25.6	53.9
Biliary intervention	14	20	182	40.0	1.9	100	20.0	34.6	50.1
MCU	16	39	531	16.7	0.6	156	6.0	11.9	17.3
Nephrostogram	12	35	458	10.4	2.0	36.5	4.5	7.7	12.9
Nephrostomy	13	24	274	15.5	1.7	48.5	8.9	13.4	18.9
Sialogram	14	26	459	1.1	0.1	2.8	0.6	1.0	1.6
Small bowel enema	18	36	493	39.3	5.1	103	24.4	38.4	50.5
T-tube cholangiogram	18	49	401	8.0	1.0	28.2	4.3	6.6	9.9
Water soluble enema	11	22	140	19.5	2.7	40.7	12.5	18.2	26.2
Water soluble swallow	14	31	213	12.1	2.9	35.1	6.0	10.0	14.3
Coronary angiogram*	7	17	8000	30.4	11.8	60.7	22.3	25.8	36.3
Hickman line	9	25	878	2.9	0.13	8.0	1.1	2.6	4.1
Oesophageal dilation	10	17	499	18.5	0.8	121	5.3	10.5	15.6
Pacemaker	12	17	627	17.0	1.6	62.0	8.4	11.2	26.5
Retrograde pyelogram	13	21	98	10.0	3.4	19.2	5.7	8.7	13.0

* Mean weight range 75-85 kg

TABLE 13 Complete examinations (dose-area product data): mean patient characteristics and exposure parameters for selected dataset

Examination	Patient age (years)	Patient weight (kg)	Radiographic tube potential (kV)	Fluoroscopy time (seconds)	No. of film-screen images per exam
Barium follow through	49(16-99)	68(32-156)	82(50-120)	118(6-1200)	3(1-13)
Barium enema	62(16-99)	69(30-190)	89(50-125)	132(2-5400)	4(1-56)
Barium meal	59(16-98)	69(30-175)	84(50-120)	114(4-2040)	5(1-49)
Barium swallow	62(16-99)	68(30-170)	83(50-120)	104(3-5400)	6(1-90)
ERCP	66(16-99)	69(35-170)	81(50-120)	271(3-3756)	4(1-90)
Femoral angiogram	67(16-97)	71(32-164)	77(50-120)	241(6-6780)	20(1-99)
Hysterosalpingogram	31(16-99)	68(34-146)	78(50-120)	56(6-5400)	2(1-8)
IVU	54(17-92)	72(35-134)	71(60-117)	38(6-468) *	6(1-25)
Venogram(leg)	55(16-93)	71(35-127)	74(50-120)	108(6-2352)	5(1-27)
Biliary drainage	71(28-95)	69(45-132)	79(50-120)	807(18-3276)	4(1-8)
Biliary intervention	67(27-99)	69(42-102)	82(50-120)	833(24-3900)	5(2-12)
MCU	53(17-101)	70(44-134)	80(50-120)	156(12-522)	5(1-20)
Nephrostogram	58(19-95)	71(32-147)	77(50-90)	245(6-2970)	3(1-12)
Nephrostomy	61(18-88)	70(38-118)	81(50-120)	413(6-2598)	1(1-2)
Sialogram	53(16-92)	72(41-145)	70(50-90)	85(6-528)	4(1-12)
Small bowel enema	48(17-95)	69(39-130)	88(50-120)	415(12-3456)	4(1-15)
T-tube cholangiogram	63(22-95)	70(35-134)	79(50-120)	126(6-2544)	4(1-6)
Water soluble enema	67(25-94)	70(32-105)	86(50-120)	140(18-702)	2(1-6)
Water soluble swallow	64(19-91)	70(38-131)	79(60-120)	158(12-3306)	3(1-24)
Coronary angiogram	60(16-97)	78(35-172)	78(50-120)	260(6-5880)	20(1-90)
Hickman line	50(16-93)	70(31-127)	80(50-120)	104(1-3186)	1(1-2)
Oesophageal dilation	65(18-97)	69(35-95)	79(50-120)	176(6-2148)	4(1-8)
Pacemaker	72(19-95)	70(38-109)	70(60-120)	387(1-5892)	1(1-2)
Retrograde pyelogram	58(17-95)	71(40-123)	80(50-120)	148(18-744)	5(1-16)

Note: the range from minimum to maximum for individual patients is given in brackets.
* 17% of IVU patients had fluoroscopy

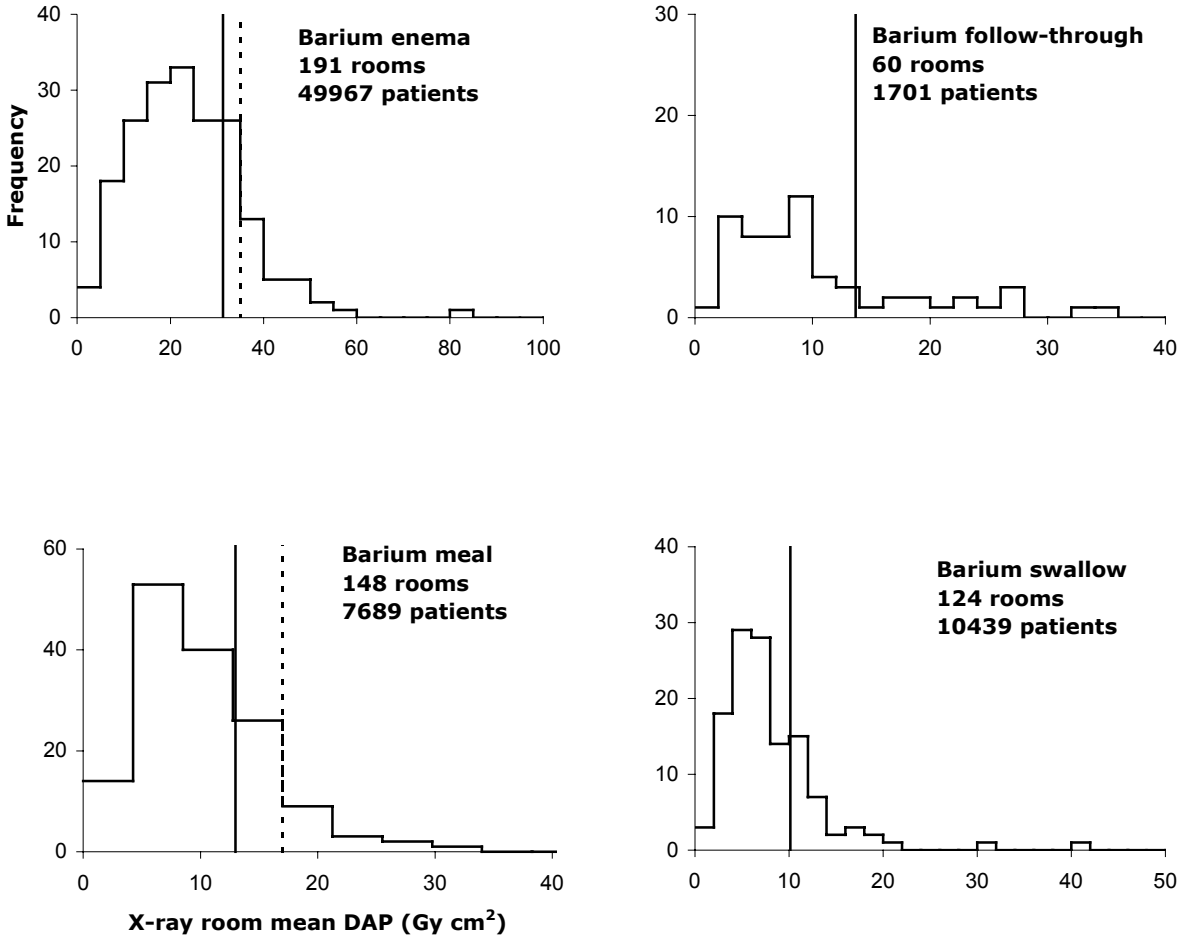

FIGURE 4 Distribution of x-ray room mean dose-area product per examination

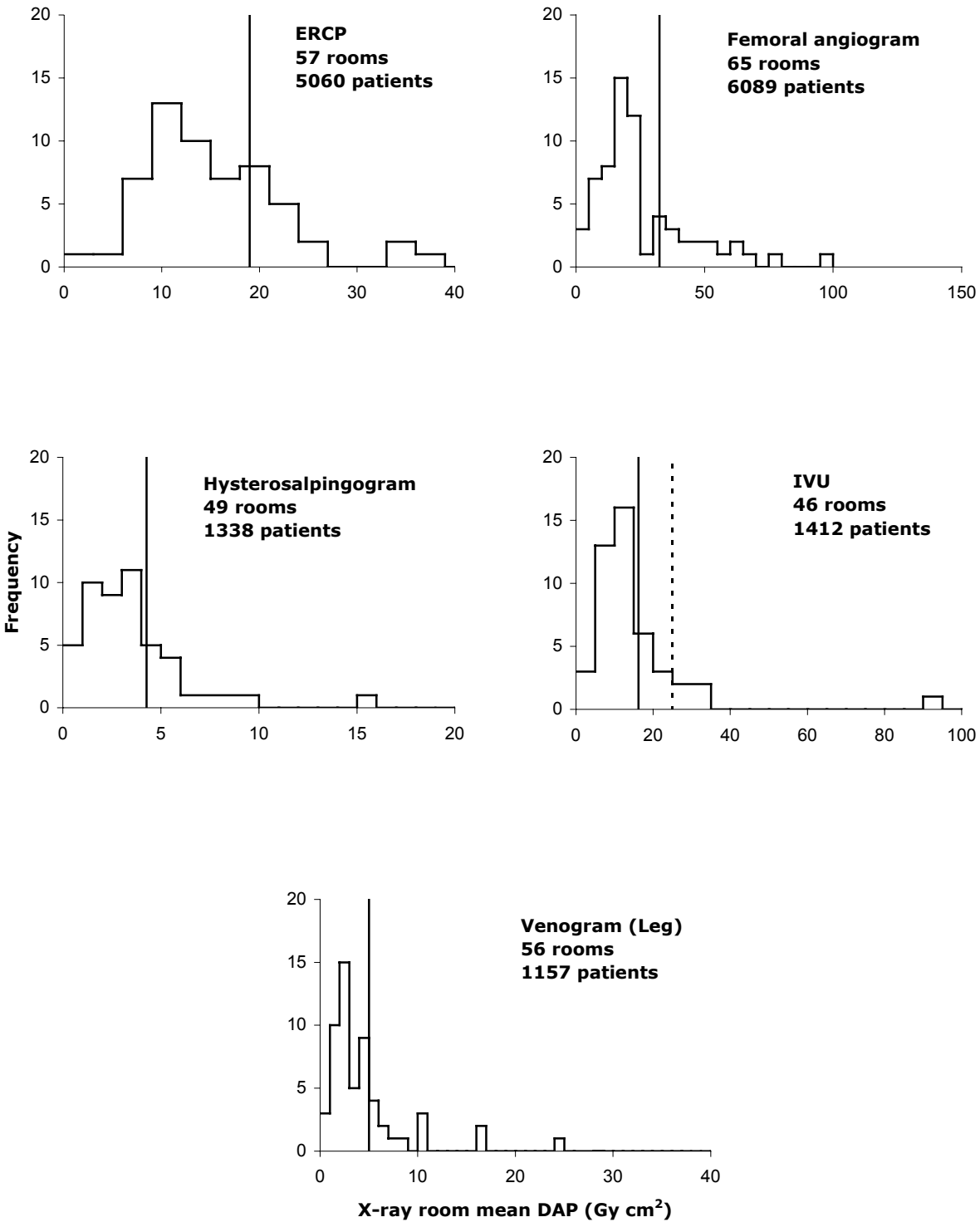

FIGURE 4 (continued)

4.4 Fluoroscopy time per examination

Dose-area product is the preferred dose quantity for complete examinations, but for any radiology rooms without DAP meters, the fluoroscopy time offers a simple alternative means of obtaining at least a partial indication of patient exposure. It makes no allowance for the influence of fluoroscopic dose rate or field size on the dose to the patient or of the contribution from any spot imaging but, if these other parameters are held fairly constant, the fluoroscopy time provides a relative indication of how the complexity of the examination and the skill of the radiologist may be affecting the dose to the patient.

Table 14 shows key parameters of the distribution of mean fluoroscopy time per room for the same examinations as listed in Tables 12 and 13. The mean, minimum and maximum fluoroscopy times shown in Table 14 are slightly different from those in Table 13, because the former are based on room mean data and the latter on individual patient data. Fluoroscopy times were not supplied for all the examinations for which DAPs were supplied, so the sample sizes in Table 14 are generally slightly smaller than in Table 12. However, all but one of the examinations still remain in the same category of sample size as listed in Table 12. The exception is intravenous urography (IVU), which is usually purely radiographic, not involving any fluoroscopy, and has therefore not been shown in Table 14.

TABLE 14 Complete examinations: summary of data on mean fluoroscopy time per room for selected dataset

Examination	No. of hosps.	No. of rooms	No. of patients	Room mean fluoroscopy time distribution (seconds) Mean	Min.	Max.	1st Quart.	Median	3rd Quart.
	>20	>40	>200						
Barium follow through	28	58	1623	116	34	499	76	109	131
Barium enema	86	177	47205	138	51	302	111	135	161
Barium meal	68	138	7009	120	32	297	87	111	139
Barium swallow	49	116	9939	110	42	459	83	101	127
ERCP	28	55	4873	265	113	596	203	249	315
Femoral angiogram	23	64	5866	256	75	896	161	215	308
Hysterosalpingogram	22	47	1276	62	18	586	40	48	62
Venogram (leg)	32	55	938	112	36	384	75	102	135
	>10	>20	>100						
Biliary drainage	10	21	201	852	156	1956	635	750	1020
Biliary intervention	14	20	181	876	102	1674	594	933	1062
MCU	16	39	525	127	14	270	91	123	163
Nephrostogram	12	35	456	200	44	562	92	144	276
Nephrostomy	13	24	273	416	30	867	309	421	531
Sialogram	12	20	436	91	29	198	74	81	98
Small bowel enema	18	34	388	500	115	1110	317	450	646
T-tube cholangiogram	18	49	399	108	6	591	72	85	121
Water soluble enema	11	22	140	127	54	202	95	121	162
Water soluble swallow	14	31	213	139	30	348	104	128	166
Coronary angiogram	7	15	6857	294	185	385	255	298	337
Hickman line	9	24	733	86	6	201	46	77	127
Oesophageal dilation	10	15	413	261	42	1144	95	141	327
Pacemaker	12	16	425	422	48	819	283	397	644
Retrograde pyelogram	13	20	96	160	78	414	127	148	178

4.5 More limited data on other examinations

There were many other types of examination for which DAP values and fluoroscopy times were provided, but they were either from an insufficient number of rooms, or were unspecified as to their exact anatomical location, and therefore did not warrant inclusion in Tables 12, 13 or 14. A brief summary of the sample size and the mean values for DAP, fluoroscopy time and radiographic kV for 43 other types of examinations from the selected dataset are shown in Table 15. An examination has been included in this table only if there was information from at least four rooms.

Although there was plenty of data for 'Angioplasty' and 'Sinogram' procedures, there was no specific information as to their anatomical location, which can have a critical effect on the patient dose. The anatomical location of 'Embolisation' and 'Thrombolysis' procedures was also not specified and, although these are clearly high-dose procedures, the radiation risk implications are difficult to interpret without knowing which organs and tissues are being irradiated. Only those ERCPs from four rooms that were clearly specified as being purely diagnostic are shown in Table 15. They have a mean dose of 7 Gy cm^2 which is about half of that given in Table 12 where the ERCPs are unclassified and are presumably a mixture of diagnostic and interventional procedures.

Data on the DAP values for complete abdomen, chest, lumbar spine and pelvis examinations were not included in Table 12, because the sample sizes were too small for abdomen, chest and pelvis examinations and more detailed information is available for lumbar spine examinations in Table 10 on the DAP values for each component radiograph.

Although the data in Table 15 are insufficient in terms of sample size or anatomical location to provide reliable reference doses, it is hoped that the information may be useful to those seeking some indication of typical practice and patient doses for these types of examination. In particular, there are several high dose angiographic and interventional procedures listed in this table that have only been performed in recent years, and for which dose data from other sources may be quite scarce. Mesenteric angiograms and rectal stents both appear to be very high dose procedures. Unfortunately, data for the reportedly very high-dose procedure TIPS (transjugular intrahepatic portosystemic shunt) were received from only three rooms in two hospitals; insufficient even to include it in Table 15.

TABLE 15 Summary of data on other examinations

Examination	No. of hosps.	No. of rooms	No. of patients	Mean of room mean DAP (Gy cm^2)	Mean of room mean fluoro. time (s)	Mean tube voltage (kV)
Abdomen	7	15	500	3.1	-	69.2
Angiogram (Abdomen)	3	7	357	97.2	436	81.7
Angiogram (Carotid)	5	8	92	34.6	675	81.6
Angiogram (Cerebral)	4	7	605	91.8	488	89.4
Angiogram (Mesenteric)	5	7	92	175.2	1092	82.9
Angiogram (Pulmonary)	3	4	36	69.6	377	79.9
Angiogram (Renal)	7	10	101	48.5	341	80.5
Angiogram (R+L Ventricle)	1	4	231	26.4	497	70.0
Angioplasty	17	40	1370	17.8	450	75.3
Aortogram (Arch)	9	13	69	31.8	347	76.4
Arthrogram (Knee)	2	4	20	1.5	95	60.8
Arthrogram (Shoulder)	6	7	56	2.3	97	75.2
Biopsy (Lung)	6	7	18	1.8	82	89.4
Bladder Pressure	5	10	1731	4.9	69	80.0
Chemical Sympathectomy	6	8	258	3.7	100	79.8
Chest	13	16	745	0.2	-	87.8
Chest Screening	13	23	87	4.6	137	80.8
Cholangiogram	3	5	17	8.0	97	70.7
Cervical spine	4	4	43	0.4	-	-
Electrophysiology	3	7	78	17.1	653	74.9
Embolisation (Testicular)	6	12	55	24.0	577	77.8
Embolisation	8	17	161	91.5	1307	90.7
ERCP (Diagnostic)	2	4	587	7.1	137	72.2
Facet Joint Injection	5	9	233	4.6	77	69.3
Fistulogram	7	14	95	11.9	155	76.4
Herniogram	8	12	76	16.4	143	82.8
Lumbar spine	27	39	766	4.6	-	83.9
L Ventricle & Aortogram	2	4	19	25.7	448	70.0
Myelogram	3	4	41	24.6	285	81.8
Nasogastric Tube	9	14	61	16.6	282	75.4
Pelvis	6	13	529	3.3	-	68.1
Pouchogram	3	8	32	13.0	85	90.6
Proctogram	9	16	302	23.8	149	93.1
PTCA (single artery)	4	4	334	63.4	878	-
RF Ablation	3	5	209	33.1	1454	72.0
Sinogram	15	36	187	8.1	122	75.4
Stent (Oesophageal)	7	9	43	29.6	563	78.2
Stent (Rectal)	3	5	18	124.6	1223	89.6
Stent (Superior vena cava)	6	7	36	41.6	487	83.0
Stent (Ureteric)	6	13	92	23.0	672	80.4
Thrombolysis	4	5	84	72.4	1348	76.8
Urethrogram	11	19	54	4.9	116	75.4
Venacavogram (inferior)	3	4	4	23.2	117	75.0

ERCP = endoscopic retrograde cholangio-pancreatography, PTCA = percutaneous transluminal coronary angioplasty, RF Ablation = radiofrequency cardiac catheter ablation.

4.6 Paediatric data

We have applied the methods described in NRPB-R318[12] to the limited amount of paediatric data in the NPDD for which the patient thickness or both the height and weight were available. This enabled us to adjust the ESD per radiograph and DAP per examination measurements made on children of known size to values appropriate for children of the nearest standard size. Five standard sizes are available corresponding to newborn babies and 1, 5, 10 and 15 year old children. The main parameters of the distributions of room mean doses after they had been adjusted in this way are shown in Table 16.

Unfortunately, for measurements of ESD per radiograph, there were data from only three rooms or less for most of the standard child sizes. The exceptions to this were Chest AP/PA radiographs for a standard 15 year old (18 cm thick), Pelvis AP radiographs for a standard 15 year old (18 cm thick), and Skull AP and LAT radiographs for standard 5, 10 and 15 year old patients. The standard head thicknesses for 5, 10 and 15 year old patients are the same (18.5 cm AP thickness and 14.5 cm LAT thickness), so it is easier to collect data from a wider range of patient ages for radiographs of the head. Even so, it can be seen from Table 16 that data were available from only 6 or 7 rooms for these exceptional types of radiograph and standard patient age. This is insufficient to be representative of national practice and to derive reliable national reference doses.

Although very few in number, the results for Chest AP/PA radiographs indicate a much less distinct trend in ESD with age than for radiographs of other parts of the trunk, confirming what was found previously[12]. This is presumably due to the relative low attenuation of x-rays through the lungs and the consequently small changes in the ratio of entrance to exit dose as the chest increases in size with age.

There was a sufficent amount of data on DAP per examination and patient size to consider setting national paediatric reference doses for just three examinations: micturating cystourethrograms (MCUs), barium meals and barium swallows. These are also shown in Table 16. It can be seen that these examinations had much bigger sample sizes, in terms of numbers of patients (514-2209) and numbers of rooms (16-29), than were available for the measurements of ESD per radiograph. A distinct upward trend in the mean and quartile values as the standard age (and size) increases, can be seen for all three examinations. However, there are only small differences between the mean and quartile values of the doses adjusted to the 1 year old and 5 year old standard patient. Conversely, the mean values of the doses adjusted to the standard newborn baby size are about a factor of two lower than those for the 1 year old and 5 year old; and those for the standard 10 year old are about a factor of two higher. The implications of these findings on the setting of national paediatric reference doses are discussed in section 6.2.

TABLE 16 Analysis of paediatric data

Standard age (years)	No. of rooms	Min.	1st quart	Median	Mean	3rd quart	Max.
		Normalised ESD/radiograph (µGy)					
Abdo AP (72 patients)							
0	1				110		
1	2	270			340		400
5	3	380	500	610	590	700	780
10	2	520			860		1200
15	3	790	1300	1700	2010	2600	3450
ChestAP/PA (142 patients)							
0	3	30	40	50	60	70	90
1	3	60	80	90	80	90	90
5	3	50	60	60	110	150	230
10	2	60			70		80
15	7	60	80	90	110	100	240
Pelvis AP (142 patients)							
0	3	110	130	150	170	210	260
1	2	310			350		390
5	2	400			510		620
10	3	500	600	650	650	730	800
15	7	550	860	970	1300	1320	3550
Skull AP (65 patients)							
1	2	370			600		840
5	6	580	780	1160	1250	1370	2520
Skull LAT (70 patients)							
1	2	250			340		420
5	6	90	420	640	580	820	860
		Normalised DAP/examination (mGycm^2)					
MCU (2209 patients)							
0	25	70	150	260	430	410	2100
1	29	70	350	640	810	900	3450
5	28	150	320	700	940	1140	4200
10	28	140	840	1280	1640	2110	5900
15	22	70	1020	1940	3410	4660	17200
Barium meal (948 patients)							
0	17	80	350	520	760	730	3100
1	20	280	740	1380	1610	1920	5080
5	19	340	840	1200	1620	1950	4800
10	23	660	2060	2580	3190	4510	6870
15	19	490	2730	4290	5670	7210	20300
Barium swallow (514 patients)							
0	18	80	180	390	560	810	1630
1	19	20	450	750	1150	1640	4460
5	16	260	490	900	1010	1250	2500
10	18	450	1420	2220	2400	2690	6170
15	17	540	1330	2860	3170	4600	7600

5 INFLUENCE OF IMAGING EQUIPMENT OR TECHNIQUE ON PATIENT DOSE

5.1 Film-screen speed

Information on the make and type of x-ray film and intensifying screen and/or the speed class of the film-screen combination was provided for about 35% of the ESD per radiograph or DAP per radiograph measurements in the database (see Table 3). Appendix C lists all the makes and types of film-screen combination for which information was provided to the NPDD between 1996 and 2000. The speed-class given in Appendix C is the manufacturer's quoted speed rating, apart from those that are asterisked, for which the mean of a set of independent measurements has been used, where that differs substantially from the manufacturer's rating. Table 17 shows the percentage of film-screen combinations of various speeds for which data were provided in the current (2000) and previous (1995)[2] reviews of the NPDD and in the national patient dose survey conducted in the mid-1980s[5].

TABLE 17 Percentage use of the different film-screen speed classes

	Percentage use		
Speed-class	2000 review	1995 review	1980s survey
50	1.2		
100/150	2.1	2.2	6
200	5.3	18.1	71
250/300	12.2	19.7	
400	66.8	52.7	23
600	10.9	6.6	
700/800	1.5	0.7	

Whereas speed-class 200 was most common in the mid-1980s, speed-class 400 is the most common in both the 1995 and 2000 review data. The table shows that the use of film-screen combinations in speed-classes greater than 200 rose from 23% in the mid-1980s, to 80% in the 1995 review, and to 91% currently. Speed-class 50 appears in the current review data, whereas it did not in the 1995 review, because much more data on examinations of the extremities (mainly ankle, knee and wrist) were supplied for the latest review. The higher spatial resolution provided by low speed-class film-screen combinations is often required when x-raying extremities to detect hairline fractures. Low speed-class combinations are also used in mammography, but the NPDD does not cover this type of radiography since the NHS Breast Screening Programme keeps it under review.

Taking a weighted average over each of the columns of Table 17, the mean speed used in the mid-1980s was 250, in the 1995 review it was 350 and for the

current review it is 390. This change in mean speed would be expected to lead to a 10% reduction in mean ESD values between the 2000 and the 1995 reviews.

5.2 Conventional or digital imaging equipment

Over the last few years, digital radiography and spot imaging systems have become more commonly used. Digital systems have the potential to increase patient doses if they are not used carefully. The wide dynamic range of digital systems allows the capture of image information over a wider exposure range than for conventional film-screen systems and the automatic post-processing of the acquired data prior to image display means that the appearance of the image provides no feedback on the level of exposure. Levels of over- or under-exposure are not evident from the optical densities in the image, as is the case with conventional film-screen radiography. Thus it is easy for the unwary operator to use higher (or lower) doses than required. Digital spot images can also be acquired and displayed instantly at the push of a button, whereas film-screen images take considerable time to be processed. The ease of acquiring digital spot images can encourage the production of more images than are necessary, thus increasing patient dose.

We have examined the data in the NPDD on computed radiography and digital spot imaging to see if either of these digital systems have had a noticeable effect on the dose to the patient. Computed radiography involves substituting an imaging plate for the cassette in a film-screen system. The plate consists of a photostimulable phosphor screen which, after irradiation, is stimulated by a scanning laser beam, to release the deposited energy in the form of visible light. The released light is converted to digital signals and sent either to a visual display unit or a printer. In digital spot imaging the signal from a TV camera looking at the output screen of an image intensifier is digitised and then processed by a computer to produce stationary spot images. Digital spot imaging is an alternative to photofluorography, in which images of the output screen of the image intensifier are directly recorded by a small format (usually 100 mm) optical camera. In this section of the report, the term 'conventional equipment' refers to systems using film-screen combinations and/or photofluorography.

No data were supplied for this current review of the NPDD from x-ray departments using the new flat panel digital imaging detectors based on an active matrix of thin film transistors, which were only just becoming commercially available at the end of the review period.

Unfortunately, out of the 28,000 measurements of ESD per radiograph in the database, only 2% were stated as having used computed radiography systems, 80% used conventional film-screen systems, and 18% were unknown. It is quite possible that many of these 18% 'unknowns' were in fact using computed radiography, since only towards the end of the review period was information on computed radiography use specifically requested. In view of the scarcity and unreliability of these data on computed radiography use, no further analysis was attempted.

However, of the 140,000 examinations for which DAP measurements were obtained, 72% were stated as using digital imaging equipment, 18% conventional equipment, and only 10% were unknown. Table 18 shows a comparison, for conventional imaging and digital spot imaging, of the mean total DAP for each of 15 examinations that are fairly common in the database. It can be seen that for all the examinations listed, digital spot imaging systems are now more commonly used than conventional imaging systems. The examinations performed with digital spot imaging have a lower mean DAP (by between 20-50%) than conventional techniques for 8 out of 16 examinations and for the other 8 the mean DAP values are not significantly different (<20%). It should be remembered that digital spot imaging is only a part of these complex examinations and the dose from fluoroscopy may be more important. However, the data in Table 18 does not appear to support the fear expressed at the beginning of this section that digital spot imaging might lead to generally higher patient doses.

TABLE 18 Effect of conventional and digital spot imaging equipment on DAP per examination – 2000 review

	Conventional		Digital spot imaging	
Examination	Mean DAP (Gy cm^2)	No. of rooms	Mean DAP (Gy cm^2)	No. of rooms
Barium enema	25.9	65	20.0	101
Barium follow through	13.1	38	7.9	90
Barium meal	12.9	65	8.9	104
Barium swallow	8.3	50	6.3	104
ERCP	14.0	10	13.5	63
Hysterosalpingogram	17.3	18	2.7	75
IVU	16.0	30	8.0	26
MCU	5.4	24	4.0	98
Nasogastric tube	12.4	12	12.3	41
Nephrostogram	9.3	16	9.6	64
Pouchogram	19.4	13	19.4	23
Retrograde pyelogram	10.7	14	9.5	58
Small bowel enema	40.1	17	32.0	55
Sinogram	7.3	18	7.2	86
T tube Cholangiogram	10.4	13	7.8	86
Venogram	7.8	32	7.0	91

Table 19 shows, for four common examinations, the mean number of images taken per examination with three different techniques, conventional film-screen, photofluorography, and digital spot imaging. The number of images tabulated is the mean for those cases where the relevant technique was used in the selected dataset. For comparison, information is also tabulated on the number of images (films) per examination in the previous 1995 review[2] and the NRPB mid-1980s survey[5]. Photofluorography and digital spot imaging are alternatives to each other, not used together in the same examination. Film-screen techniques may

either be the sole source of images for an examination, or may be used in conjunction with either photofluorography or DSI. The mean number of images shown in the table for film-screen techniques in the 2000 review is therefore the average of these three cases. It is therefore not possible to combine the last three columns of the table into a total number of images for each examination in the 2000 review. However, it is possible to compare the number of images taken with photofluorography and DSI, where there is a tendency for the latter to be higher for three out of the four examinations.

TABLE 19 Mean number of images per examination

	1980s survey	1995 review	2000 review		
	Film-screen	Film-screen	Film-screen	Photofluor-ography	DSI
Barium enema	9	10	4	8	9
Barium follow through		4	3	4	8
Barium meal	8	11	5	14	13
Barium swallow		24	6	16	21

Measurements of ESD/radiograph were received from one hospital for a Philips Thoravision system. This system is used for chest radiography, and employs a selenium-coated drum as the x-ray detector. Radiation exposure produces a latent electrostatic image on the selenium surface, which is read out from the rotating drum by electrometer probes. After digital processing, the image is displayed on a monitor. The mean ESD using Thoravision for chest PA for 99 patients (mean weight 65 kg) was 0.13 mGy. The mean ESD for chest PA for all adults in the database (mean weight 71 kg) was 0.15 mGy. Since the change in dose per kilogram for chest PA is typically 1.7%[13], the 10% difference in dose between these two datasets would be expected from the difference in mean weight alone. These data consequently provide no clear evidence for a reduction or increase in dose when using Thoravision instead of conventional film-screen chest radiography.

5.3 High kV technique for chest PA

Examination of the applied potential on the x-ray tube for more than 5000 adult chest PA radiographs shows a bi-modal distribution (see Figure 5) with the larger peak at 65-70 kV and the smaller peak at 120-125 kV. European Commission guidelines on quality criteria for diagnostic radiographic images[14] recommended the use of tube voltages of 125 kV for chest radiographs. Taking the bulk of the data from around these two modes, the mean ESD for the 3892 radiographs

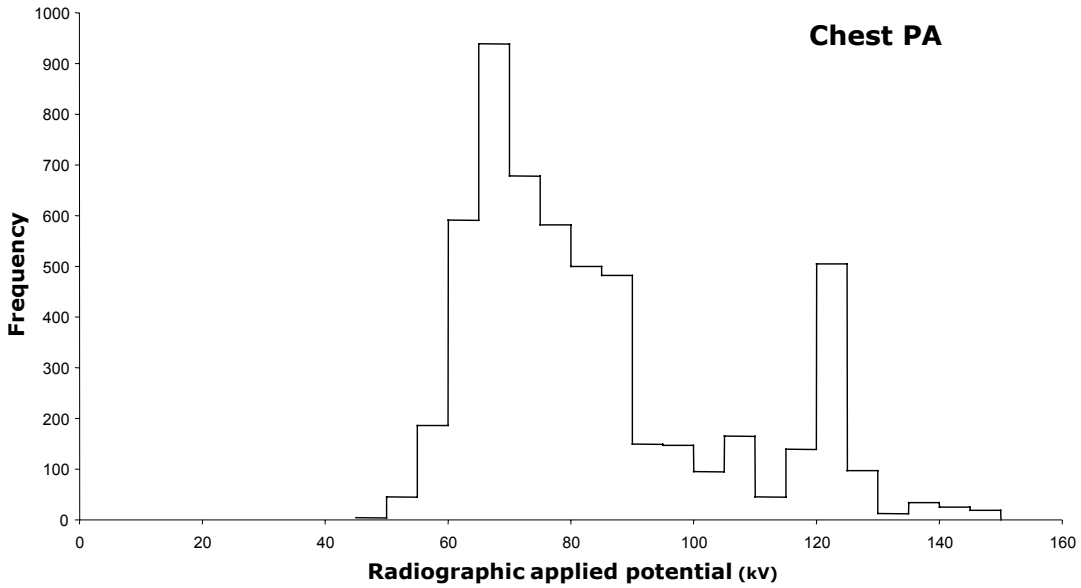

FIGURE 5 Frequency of radiographic applied potential for chest PA

taken at 60-90 kV was 0.14 mGy, and the mean ESD for the 929 radiographs taken at 110-150 kV was 0.19 mGy (i.e 35% higher). Table 20 shows the mean values of some parameters, in addition to tube voltage, that might influence these doses.

TABLE 20 Parameters influencing ESD for low and high kV chest radiographs

	Low kV (60-90)	High kV (110-150)
Mean ESD (mGy)	*0.14*	*0.19*
Mean patient weight (kg)	71.0	71.3
Mean film-screen speed	378	350
Mean FSD (cm)	154	200
Mean FFD (cm)	178	209

The table shows that mean patient weight is very similar for the two techniques. The faster film-screen speed for the low kV technique would be expected to reduce doses by only about 7%, i.e. not enough to explain the 35% lower values. The longer FSDs and FFDs used for the high kV technique should reduce the dose. Therefore none of the tabulated parameters fully explain the difference in dose for the two techniques.

A further factor that will influence the dose is the use of an antiscatter grid. Unfortunately, information about whether a grid was used or not, was supplied for less than 10% of these measurements. However, the information, where provided, was that a grid was usually used with the high kV technique, and was never used with the low kV technique. Typical grid parameters were a grid ratio

of 11, and 40 strips/cm. This is similar to the type of grid recommended by the European Commission[14] (grid ratio of 10 and 40 strips/cm). For grids of this type the grid factor (the ratio of exposure with the grid to exposure without the grid) is typically about 5 at a high kV[15,16].

The corresponding ratio in mean ESD values seen in the 10% of the chest PA data where information on grid use was available, was 2.1 (i.e. when a grid was definitely used the mean ESD was 0.27 mGy and when a grid was definitely not used the mean ESD was 0.13 mGy). Thus the most likely explanation for the 35% higher doses seen in general for the high kV technique is that antiscatter grids are used more often than with the low kV technique to maintain image contrast. The high kV technique is thus not generally being applied in such a way as to reduce patient doses.

6 DISCUSSION

6.1 Trends in patient doses with time

In comparison with earlier surveys the results from this current review indicate a continuing downward trend in doses for most of the common radiographs and examinations studied. Figure 6 shows the trends in the mean value of the room mean ESDs between the mid-1980s survey[5], the 1995 review[2] and the present review, for all types of radiograph except those of the chest. All show a distinct downward trend with time. Statistical tests (Student's t) on the data indicated that the differences between the corresponding mean values for the mid-1980s and the 1995 review were statistically significant at more than the 99% confidence level for all but the thoracic spine projections[2]. Similar tests on the differences between the mean values in the 1995 and 2000 review indicate that they are statistically significant at more than the 99% confidence level for all but the PA and lateral chest projections. The mean ESD for PA chest radiographs showed an insignificant 7% reduction between 1995 and 2000. For lateral chest radiographs there was an apparent 50% increase, but the sample sizes were small for both reviews (41 and 28 rooms respectively) and this difference was statistically significant at only the 90% confidence level.

Figure 7 shows the trends in the mean value of the room mean DAPs for the five types of examination where we have sufficient data. These also show a general downward trend, with the exception of IVUs, which have slightly increased between the 1995 and 2000 reviews. However, the 1995 mean was based on data from only 10 rooms and the difference between it and the 2000 mean is not statistically significant (<50% confidence level).

There has been an overall average reduction of 16% since the 1995 review in the mean dose for all the radiographs and examinations in Figures 6 and 7. The increase in film-screen speeds since the last review could account for about 10% of the reduction for the radiographic examinations (see section 5.1). Another factor, which may be helping to reduce the doses for the barium examinations in Figure 7, is the increasing use of digital spot imaging (see section 5.2). There is no clear evidence for a reduction in the number of images taken or in the duration of fluoroscopy for these barium examinations.

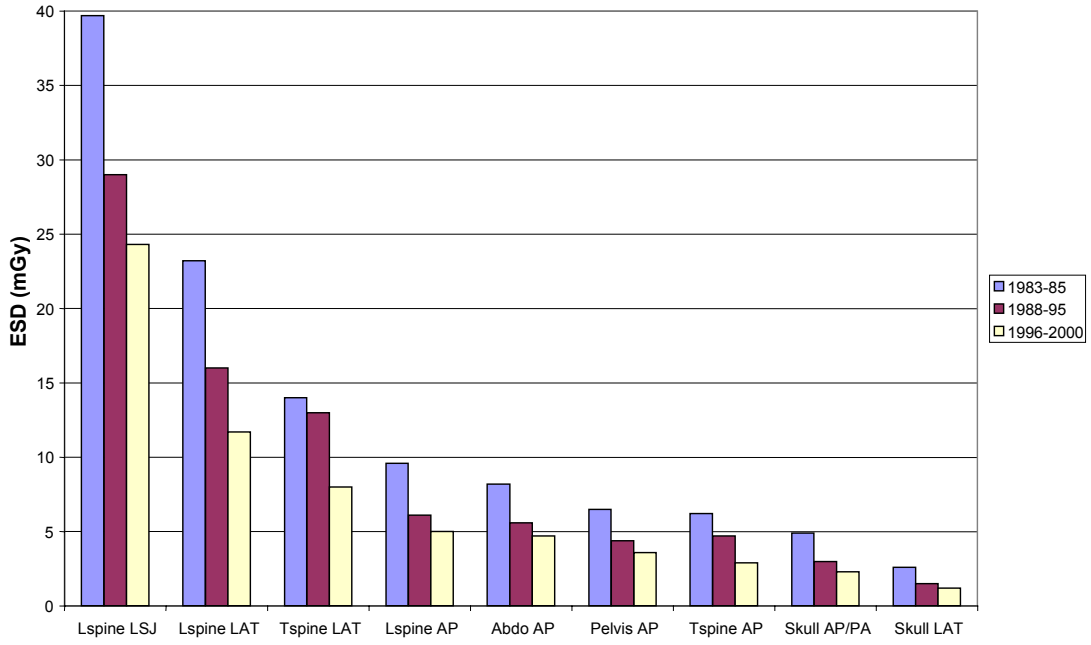

FIGURE 6 Mean entrance surface dose per radiograph

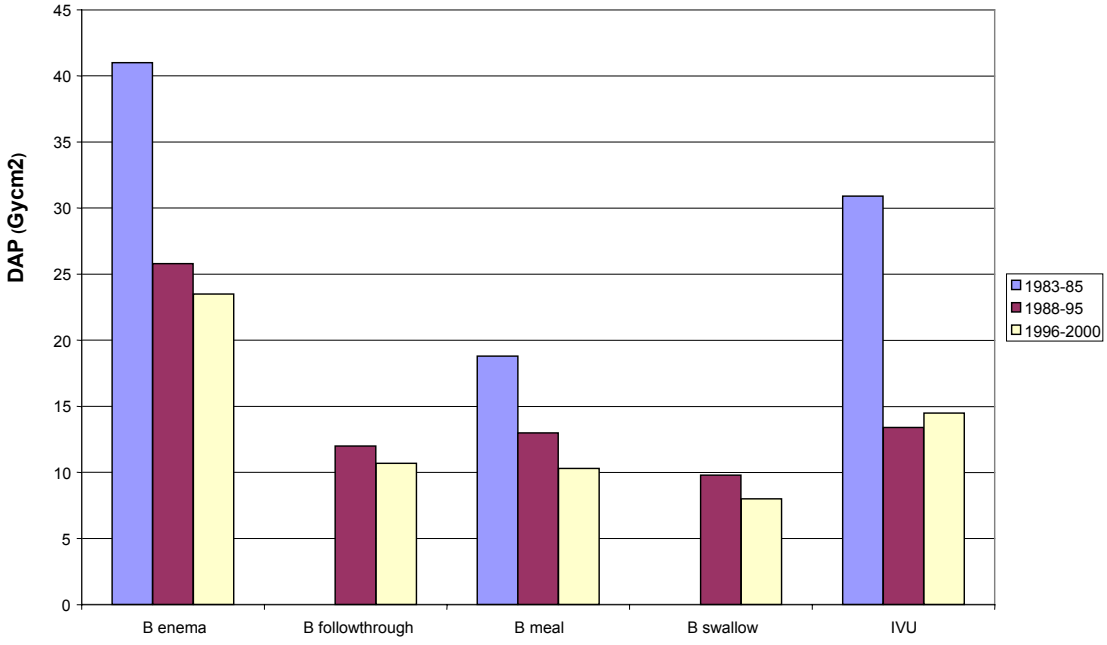

FIGURE 7 Mean dose-area product per examination

Whereas there has been a general reduction in the mean values of the room mean dose distributions since the 1995 review, the width of the distributions (i.e. the range of the room mean doses) is similar to or larger than before. Table 21 shows the ratio of maximum to minimum, 3rd to 1st quartile and the coefficient of variation for the room mean dose distributions for most of the radiographs and examinations for which we have data from about 20 rooms or more. Comparable data from the 1995 review are shown where available.

The ratio of maximum to minimum is often considerably greater for the current review than for the 1995 review. However this measure of the width of the distributions is based on just two datapoints and, as can be seen from the histograms in Figures 2-4, there is often one extreme high-dose outlier that has an overwhelming influence on the maximum to minimum ratio. This at least suggests that data from rooms with exceptionally high doses are not consistently being witheld from the national database, and helps to justify the assumption that the sample is not biased toward lower doses due to being voluntarily supplied. The ratio of the third to the first quartile is much less sensitive to extreme values and, when averaged over all comparable radiographs and examinations, is the same (2.2) for both the 2000 and the 1995 reviews.

The coefficients of variation of the room mean dose distributions range from 50-100% for all types of radiograph and examination (except MCUs and oesophageal dilations) and are on average about 10% higher for the 2000 compared to the 1995 review. It is interesting to note that the coefficients of variation for other types of interventional and complex procedures apart from MCUs and oesophageal dilations (eg. biliary interventions, femoral and coronary angiograms) are no greater than those for individual radiographs. Whereas much greater variabiltiy in **individual patient doses** might be expected for complex and interventional procedures that have to be adapted according to patient need, the variation in **room mean doses** averaged over a representaive sample of patients does not appear to be systematically larger for these complex procedures than for simple radiographic examinations. If this is so, the use of reference doses based on the observed distribution of room mean doses, would still appear to be a useful aid to the optimisation of complex and interventional procedures, despite an expectedly large patient to patient variation.

Table 21 Ratio of x-ray room mean dose values

	Maximum/minimum		3rd/1st quartile		Coefficient of variation (%)	
	2000	1995	2000	1995	2000	1995
	X-ray room mean ESD					
Skull AP/PA	14	20	2	1.9	60	42
Skull LAT	31	8	2.3	1.8	56	51
Chest PA	150	94	2.3	1.7	80	63
Chest LAT	25	24	3.2	2.0	104	75
Tspine AP	67	14	1.6	1.8	49	70
Tspine LAT	108	33	2.4	2.7	62	72
Lspine AP	214	22	1.8	1.8	87	61
Lspine LAT	283	19	1.9	2.0	80	59
Lspine LSJ	163	20	1.8	1.9	78	54
Abdo AP	52	22	1.7	2.0	46	53
Pelvis AP	64	16	1.8	1.8	53	51
	X-ray room mean DAP					
Ba swallow	31	9	2.1	2.1	67	66
Ba meal	38	18	2	2.4	53	65
Ba follow	21	10	2.9	2.6	75	75
Ba enema	29	11	2.1	2.0	50	56
Small bowel enema	20	8	2.1	4.8	58	80
IVU	56	7	2.4	3.7	93	71
MCU	260	1.5	2.9	1.3	149	20
Biliary drainage & intervention	53	-	4.4	-	70	-
Femoral angiogram	87	-	2.2	-	73	-
T-tube cholangiogram	28	2	2.3	-	68	46
Hysterosalpingogram	39	-	2.4	-	77	-
Venogram (leg)	60	3	2.4	1.5	94	47
Nephrostogram	18	-	2.9	-	84	-
Nephrostomy	29	-	2.1	-	70	-
Sialogram	28	-	2.7	-	61	-
Hickman line	62	-	3.7	-	77	-
Retrograde pyelogram	6	-	2.3	-	48	-
Coronary angiogram	5	-	1.6	-	21	-
Pacemaker	39	-	3.2	-	94	-
Oesophageal dilation	151	-	2.9	-	155	-

6.2 National reference doses

NRPB recommendations for national reference doses are based on rounded third quartile values for the room mean dose distributions observed in national surveys of patient doses. Reference doses set at this level are intended to be a simple indication of abnormally high doses. They act as a trigger to just the first step in the optimisation of patient doses - the identification of those practices in most urgent need of investigation and corrective action, if they cannot be clinically justified. Guidance on the purpose and means of implementing national reference doses has been published by NRPB in collaboration with the appropriate professional bodies[1,3,4]. Following the enactment of the IR(ME)R 2000[6], with requirements for the implementation of 'diagnostic reference levels' (DRLs) in the UK, the Department of Health agreed that NRPB's recommended 'national reference doses' would be considered when setting and reviewing 'national DRLs'[7]. For this regulatory purpose, 'national DRLs' are set by the Department of Health's DRL Working Party.

The following sections discuss NRPB's previous and current recommendations on national reference doses.

6.2.1 Adult patients

Rounded third quartile values for typical adult patients were derived from our national survey in the mid-1980s and from the 1995 review of the NPDD, in terms of the ESD for 11 types of radiograph and the DAP for 3 types of complete examination. Corresponding values from the current 2000 review are compared with the earlier values in Table 22.

There has been a continuing reduction in the third quartile values with time, for all types of radiograph and examination except for the PA and lateral chest radiographs, which show an insignificant reduction or a slight increase between the 1995 and 2000 reviews. The average reduction in the third quartile values in Table 22 between 1995 and 2000 (including the slight increase for chest LAT) has been 19%. This is, not surprisingly, similar to the average reduction in the **mean** dose for common radiographs and examinations of 16% discussed in section 6.1. It is interesting to note that the third quartile values have approximately halved in the 15 or so years since the original survey in the mid-1980s.

TABLE 22 Rounded third quartile values from the current and previous reviews of national patient dose data

Radiograph or examination	Rounded third quartile values		
	Mid-1980s Survey	1995 review	2000 review
	ESD per radiograph (mGy)		
Skull AP/PA	5	4	3
Skull LAT	3	2	1.6
Chest PA	0.3	0.2	0.2
Chest LAT	1.5	0.7	1
Thoracic spine AP	7	5	3.5
Thoracic spine LAT	20	16	10
Lumbar spine AP	10	7	6
Lumbar spine LAT	30	20	14
Lumbar spine LSJ	40	35	26
Abdomen AP	10	7	6
Pelvis AP	10	5	4
	DAP per examination (Gy cm^2)		
IVU	40	25	16
Barium meal	25	17	13
Barium enema	60	35	31

In the current 2000 review there are data from a sufficient number of rooms to set reference doses that are representative of national practice for a much larger selection of examinations than was possible previously. On the assumption that a minimum of 20 rooms is necessary, reference doses can be recommended for an additional 14 types of complete examination, in terms of both DAP and fluoroscopy time. There are also sufficient data on DAP per radiograph to recommend reference doses in terms of this quantity for 6 of the 11 types of radiograph for which ESD reference doses are available. The latest set of recommended national reference doses for individual radiographs on adult patients is shown in Table 23. The number of rooms supplying data for each radiograph is also indicated in the table. Due to the way in which DAP measurements take account of the x-ray beam area and the radiation dose, it is perhaps just a coincidence that the last four radiographs in the Table (lumbar spine LAT, lumbar spine LSJ, abdomen AP and pelvis AP) all share the same DAP reference dose.

Table 23 Recommended national reference doses for individual radiographs on adult patients – 2000 review

Radiograph	ESD per radiograph (mGy)	No. of Rooms	DAP per radiograph (Gy cm^2)	No. of rooms
Skull AP/PA	**3**	48	**-**	-
Skull LAT	**1.5**	38	**-**	-
Chest PA	**0.2**	415	**0.12**	111
Chest LAT	**1.0**	28	**-**	-
Thoracic spine AP	**3.5**	47	**-**	-
Thoracic spine LAT	**10**	50	**-**	-
Lumbar spine AP	**6**	289	**1.6**	89
Lumbar spine LAT	**14**	362	**3**	91
Lumbar spine LSJ	**26**	107	**3**	43
Abdomen AP	**6**	280	**3**	85
Pelvis AP	**4**	306	**3**	100

Similarly the latest set of national reference doses for complete examinations, in terms of both the total DAP and the total fluoroscopy time (expressed in minutes) for the examination, is shown in Table 24. The number of rooms supplying data for each examination is also indicated in the table. Examinations of the gastro-intestinal tract are shown first followed by other diagnostic and interventional procedures in alphabetical order. Three additional diagnostic or interventional procedures have been included at the bottom of Table 24, which might be of interest because they are fairly common and involve fairly high doses, but do not quite meet the assumed minimum requirement of 20 rooms.

Water-soluble enemas and swallows have been combined with barium enemas and swallows and given the same reference doses in Table 24, since the respective DAP and fluoroscopy time values in Tables 12 and 14 are fairly similar for these examinations when performed with the two types of contrast media. The biliary drainage and biliary intervention procedures described separately in Tables 12 and 14, have also been combined in Table 24, for the same reason. It should be remembered that the data for coronary angiograms relate to patients with a mean weight of 78 kg, as discussed in section 4.3.

The data for ERCP examinations shown in Tables 12 and 14 have been omitted from Table 24 because a clear distinction between purely diagnostic ERCPs and interventional ERCPs was made for only a few of the rooms supplying data. Most of the room mean doses and fluoroscopy times relate to an unknown mixture of diagnostic and interventional ERCP procedures. Analysis of the small amount of data where the diagnostic or therapeutic nature of the procedure was specified, indicated that room mean DAPs and fluoroscopy times were about 3 times higher for interventional compared to diagnostic ERCPs. For the bulk of the data, which is presumably a mixture of diagnostic and interventional procedures, the mean of the room mean DAPs and fluoroscopy times are about twice those for the purely diagnostic procedures. More clearly specified data are

Table 24 Recommended national reference doses for complete examinations on adult patients – 2000 review

Examination	DAP per exam (Gy cm^2)	No. of Rooms	Fluoroscopy time per exam (mins)	No. of Rooms
Barium (or water soluble) swallow	**11**	155	**2.3**	147
Barium meal	**13**	148	**2.3**	138
Barium follow through	**14**	60	**2.2**	58
Barium (or water soluble) enema	**31**	213	**2.7**	199
Small bowel enema	**50**	36	**10.7**	34
Biliary drainage/intervention	**54**	41	**17**	41
Femoral angiogram	**33**	65	**5.0**	64
Hickman line	**4**	25	**2.2**	24
Hysterosalpingogram	**4**	49	**1.0**	47
IVU	**16**	46	**-**	-
MCU	**17**	39	**2.7**	39
Nephrostogram	**13**	35	**4.6**	35
Nephrostomy	**19**	24	**8.8**	24
Retrograde pyelogram	**13**	21	**3.0**	20
Sialogram	**1.6**	26	**1.6**	20
T-tube cholangiogram	**10**	49	**2.0**	49
Venogram (leg)	**5**	56	**2.3**	55
Coronary angiogram	**36**	17	**5.6**	15
Oesophageal dilation	**16**	17	**5.5**	15
Pacemaker	**27**	17	**10.7**	16

required before separate reference doses can be set for diagnostic and interventional ERCP procedures.

There are five clearly interventional procedures shown in Table 24 ('Biliary drainage/intervention', 'Hickman line', 'Nephrostomy', 'Oesophageal dilation' and 'Pacemaker') in the sense that they all involve a surgical procedure. Biliary interventions have higher reference doses (54 Gy cm^2 and 17 minutes fluoroscopy time) than all other examinations, whereas insertion of a Hickman line is a fairly simple procedure and the reference doses are comparatively low.

6.2.2 Paediatric patients

As discussed in section 4.6 and shown in Table 16, there are only three examinations on children for which data are available from about 20 or more

rooms for each of the five standard sizes. The recommended national paediatric reference doses based on rounded values of the third quartiles of room mean DAP for these three examinations at each standard age corresponding to the standard size are shown in Table 25.

Table 25 Recommended national reference doses for complete examinations on paediatric patients – 2000 review

Examination	Standard age (y)	DAP per examination (Gy cm^2)	No. of rooms
MCU	**0**	**0.4**	25
	1	**0.9 (1.0)**	29
	5	**1.1 (1.0)**	28
	10	**2.1**	28
	15	**4.7**	22
Barium meal	**0**	**0.7**	17
	1	**2.0 (2.0)**	20
	5	**2.0 (2.0)**	19
	10	**4.5**	23
	15	**7.2**	19
Barium swallow	**0**	**0.8**	18
	1	**1.6 (1.5)**	19
	5	**1.3 (1.5)**	16
	10	**2.7**	18
	15	**4.6**	17

As mentioned in section 4.6, there are only small differences between the rounded third quartile values of the doses for the 1 year old and 5 year old standard-sized patient, for all three examinations. Conversely, the mean values of the doses adjusted to the standard newborn baby size are about a factor of two lower than those for the 1 year old and 5 year old standard sizes; and those for the 10 year old standard size are about a factor of two higher. In view of their numerical similarity, it would appear to be unnecessary to set different reference doses for the 1 year old and 5 year old standard-sized patients and so, as a first step it is suggested that the same reference dose be applied to both. The recommended value is shown in brackets in Table 25.

It might also be considered that 15 year old children are, on average, so close in size to adults that their doses will be similar and there is no need to provide size-corrected reference doses for children of this age. However, there are wide variations in growth rate in teenage children and age is an even less reliable indicator of size than for younger children. A size-specific reference dose for a 'standard 15 year old patient' could therefore be of considerable value. More importantly, both European and UK survey data indicate that doses to 15 year

olds, whether size-adjusted or not, tend to be significantly lower (by at least a factor of two on average) than those to adults. Separate reference doses for 15 year olds and adults would therefore appear to be necessary.

Paediatric dose data for MCUs seen in a European survey in 1998 had been analysed in NRPB-R318[12]. As in this report, the rounded third quartile values of the adjusted doses for each of the five standard ages were used to suggest provisional paediatric reference doses. Table 26 compares the provisional paediatric reference doses derived from the European data with the national reference doses for MCUs recommended in this report. The European MCU survey covered 190 patients from 11 hospitals in 7 Western European countries, whereas the NPDD data covers 2200 patients from 22 UK hospitals. Despite substantial differences in the sample of hospitals and patients studied in the two surveys, the two sets of reference doses are remarkably similar.

Table 26 Comparison of reference doses for MCUs on paediatric patients

Standard age (years)	Reference dose ($Gycm^2$)	
	2000 review of UK NPDD	1998 European survey
0	0.4	0.6
1	0.9	0.9
5	1.1	1.2
10	2.1	2.4
15	4.7	--

7 CONCLUSIONS

This review of the data held in NRPB's national patient dose database between 1996 and 2000 has demonstrated further reductions in patient doses in the UK since the last review conducted at the end of 1995. Typical (mean) doses for common radiographic and fluoroscopic x-ray examinations have dropped by an average of 16%. There is evidence that this reduction is partly due to the use of faster film-screen combinations and it may also have been assisted by the observed increase in the use of modern digital imaging equipment.

A considerably larger number of dose measurements have been analysed this time (about 180,000) than in the previous review (about 52,000). They have been contributed by 371 hospitals of all sizes from all over the UK. The survey did not involve formal sampling, but we believe that it has enabled patient dose distributions that are a reasonable reflection of national practice to be presented for about 30 different types of radiograph or complete x-ray examination on adult patients and for 3 types of examination on children. National reference

doses, based on rounded third quartile values of these dose distributions, have been recommended and are expressed in terms of entrance surface dose (ESD), dose-area product (DAP) or fluoroscopy time. The reference doses have been derived for standard-sized adults (mean weight 70 kg, apart from coronary angiography patients who have a mean weight of 78 kg) and for five standard-sized paediatric patients corresponding to new born babies, 1, 5, 10 and 15 year olds. These recommended national reference doses will be considered by a Department of Health Working Party when it reviews and sets new national diagnostic reference levels (DRLs), as required by IR(ME)R 2000.

The current reference doses are on average about 20% lower than the third quartile values seen in the 1995 review and have approximately halved since the original national patient dose survey in the mid-1980s. The procedures for regular patient dose monitoring and audit that have been encouraged in the UK since the early 1990s and are now a regulatory requirement, appear to continue to have a significant impact on patient protection. However, the variation in typical doses delivered by different x-ray rooms and departments is still substantial, indicating that there is further scope for patient dose reduction in those departments at the top end of the dose range. This verifies the continuing usefulness of reference doses for identifying them.

For the next review of the NPDD, due to begin at the end of 2005, it would be helpful if data were supplied by more hospitals particularly from those areas in the south and west of England that were under-represented in this review. It is hoped that the number of examinations for which reference doses are given can be extended to include some of the more common high-dose angiography or interventional procedures such as peripheral angiography and percutaneous transluminal coronary angioplasty (PTCA). For coronary angioplasties, information on the number of artery dilations and the number of stents fitted would help to define different complexities for this procedure, and allow the comparison of patient doses for procedures of a similar complexity. The total dose-area product (DAP) for the complete procedure is the preferred patient dose quantity, but the duration of fluoroscopy also provides a useful indication of relative patient exposure for reference dose purposes. Some of the data submitted for this review could not be used because the anatomical location of the examination or procedure was not clear from the name given (e.g. ‘angioplasty’, ‘sinogram’, ‘embolisation’ and ‘thrombolysis’). Providers of data for the next review are encouraged to include sufficient information to locate the examination more precisely. More data on patient doses for images taken with computed radiography systems (photostimulable phosphor plates) would also be welcome.

NRPB, in collaboration with medical physicists from the UK CT Users Group, is planning a new national survey of CT practice and patient doses in 2002/03. A separate national patient dose database for CT examinations will be established and maintained to form the basis for national reference doses for this increasingly important imaging modality.

8 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the co-operation of the following hospital physicists and other radiology department staff in supplying patient dose data:

J Anderson, S E Anderson, S E Brennen, L R Bridge, A Bristow, J Cashmore, C Chapman-Jones, C-L Chapple, M Cocker, M T Crawley, J Culy, M L Davies, M Dunn, J P Eatough, S C Evans, R Y L Fong, J A Hubbard, A P Hufton, A J Hunt, J E Ison, G P Jones, J R Jones, V Jones, S Knapp, J C Kyriou, J Lawson, G Leadbetter, A MacNamara, C J Martin, H K Matharu, W-L McCormick, A E Miller, M Milton, R B Mooney, G Morrison, M Nettleton, D E Peach, J Poveda, I Roberts, N P Rowles, A J Shaw, J Shekhdar, M A Smail, S Spencer, T Stewart, J E Stock, D G Sutton, D W Thomas, C Wakeham, B Walmsley, R Wharvell, L Whitehead, J R Williams, J Wright.

Please accept our apologies if anyone has been inadvertently omitted from this list.

We also thank D Bungay and E Ayres from NRPB for invaluable assistance in processing much of the data to prepare it for entry into the database.

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APPENDIX A PARTICIPATING HOSPITALS

1996- 2000

ENGLAND

Addenbrooke's
Airedale General
Alexandra (Cheadle)
Alexandra (Redditch)
Altrincham General
Annabelle Lady Boughey Cottage
Barnsley District General
Bedford General
Billinge
Birmingham Chest Clinic
Birmingham Children's
Birmingham Heartlands
Bishop Auckland General
Blackburn Royal Infirmary
Bolton Royal Infirmary
Bredon House
Bridgnorth & S.Shropshire Infirmary
Bristol General
Bristol Royal Infirmary
Brixham
Buckland
Bucknall
BUPA Health Screening Centre (London)
Burnley General
Bury General
Cambridge Chiropractic Clinic
Cambridge Lea BUPA
Central Birmingham Imaging
Central Out-Patients Department (Stoke)
Chase Farm
Chaucer
Cheltenham General
Cheshunt Community
Chesterfield & North Derbyshire Royal
Chesterfield Nuffield
Chorley & District
Christchurch
Christchurch Park
Christie
City Hospital Birmingham (Dudley Rd)
Corby Community
Cromer District
Cromwell Clinic
Croydon General
Cumberland Infirmary
Darlington Memorial
Derwent
Devonshire Royal
Dewsbury District
Doddington County
Doncaster Royal Infirmary
Droitwich Private
Dryburn
Eastbourne District General
Edith Cavell
Epsom General
Eternit UK Ltd
Evelyn
Evesham General
Exeter Nuffield
Fairfield General
Fitzwilliam
Freeman
Fulbourn
Furness General
Garden
Good Hope District General
Grantham & Kesteven General
Grosvenor Nuffield
Guildford Nuffield
Halifax General
Halifax Royal Infirmary
Hammerwich
Harbour
Harefield
Hartlepool General
Hartshill Orthopaedic
Haywood Centre
Heathrow Airport
Hemel Hempstead General
Hereford County
Hereford General
Hexham General
Highfield
Hinchingbrooke
HMP Blakenhurst
Homerton
Hope
Ilkley Coronation
Ipswich
Isebrook
James Paget
Jersey General
Jessop's Hospital for Women

John Coupland
Keighley Health Centre
Kelling
Kent & Canterbury
Kent & Sussex
Kettering General
Kidderminster General
King's Oak
Ladywell
Leek Moorlands
Leicester Royal Infirmary
Leigh Infirmary
Leominster Community
Lincoln County
Lister
Little Aston BUPA
London Chest
Longbridge
Louth County
Ludlow
Luton and Dunstable
Maidstone
Malvern Community
Manchester Royal Infirmary
Marston Green
Mayday University
Medway Maritime
Middlesbrough General
Milton Keynes General
Moseley Hall
Mount Vernon
Newcastle General
Newcastle Nuffield
Newham General
Newmarket General
Newton Abbot
Newtown Health Centre (Birmingham)
Norfolk & Norwich
North Cambridgeshire
North Sea Medical Centre
North Staffordshire
North Staffordshire Nuffield
North Tees General
North Tyneside District General
Northampton General
Northern General
Northgate
Norwich BUPA
Norwich X-ray Practice
Nottingham City
Nottingham Nuffield
Ormskirk & District General
Paignton
Papworth
Patrick Stead
Pembury
Pendle Community
Peterborough District
Pilgrim
Plymouth Nuffield
Poole
Portland Hospital for Women
Preston Hall
Princess Alexandra (Harlow)
Princess of Wales (Ely)
Princess of Wales Community
Princess Royal (Telford)
Priory
Purley & District War Memorial
Queen Elizabeth (Birmingham)
Queen Elizabeth (Gateshead)
Queen Elizabeth (King's Lynn)
Queen Elizabeth Hospital for Children
Queen Elizabeth the Queen Mother
Queen Mary's Hospital for Children
Queen Mary's University
Queen Victoria
Robert Jones & Agnes Hunt Orthopaedic
Ross Cottage
Rossendale General
Rotherham District General
Roundhay BUPA
Royal (Woodlands) Orthopaedic
Royal Alexandra Hospital for Sick Children
Royal Bournemouth General
Royal Free
Royal Hallamshire
Royal Lancaster Infirmary
Royal Liverpool Children's
Royal London
Royal Preston
Royal Shrewsbury (North & South)
Royal Sussex County
Royal Victoria
Royal Victoria Infirmary
Saffron Walden Community
Sandringham
Scunthorpe General
Selly Oak
Sevenoaks
Sharoe Green
Sheffield Children's
Sheppey
Shotley Bridge General
Silverthorne Medical Centre
Sittingbourne Memorial

Skipton General
Soho Health Centre (Hansworth)
Solihull
Solihull Parkway
Somerset Nuffield
South Bank BUPA
South Cleveland
South Tyneside District General
Southend General
St. Albans City
St. Andrew's (London)
St. Bartholomew's (London)
St. Edmund's
St. George's
St. Helier
St. Leonard's
St. Luke's
St. Margaret's (Epping)
St. Michael's (Lichfield)
St. Michael's (Aylsham)
St. Michael's (Bristol)
Stafford District General
Stamford and Rutland
Stepping Hill
Stoke Mandeville
Sunderland Royal
Sussex Nuffield
Sutton
Swaffham County
Swanage
Tameside General
Tamworth General
Tenbury Wells General
Thetford Cottage
Thornbury (Sheffield)
Torbay District General
Trafford General
Tunbridge Wells Nuffield
Uckfield Community
Victoria (Blackpool)
Victoria (Lewes)
Victoria (Wimborne)
Wansbeck General
Watford General
Wellington
West Cumberland Infirmary
West Heath
West Hill
West Norwich
West Suffolk
Westmorland
Weston General
Whipps Cross
Whitchurch Cottage
William Harvey
Withington
Worcester Royal Infirmary
Wrekin
Wrightington
Yardley Green
136 Harley St
2 anonymous hospitals in London

NORTHERN IRELAND

Antrim Area
Ards
Armagh Community
Bangor
Belfast City
Coleraine
Craigavon Area
Daisy Hill
Erne
Mater Infirmorum
North West Independent
Royal Belfast Hospital for Sick Children
Royal Maternity (Belfast)
Royal Victoria
South Tyrone
Tyrone County
Ulster
Whiteabbey

SCOTLAND

Aberdeen Royal Infirmary
Albyn
Bon Secours (Glasgow)
BUPA Health Screening Centre (Glasgow)
Dr Gray's
Fernbrae Private Clinic
Fraserburgh
Glasgow Nuffield
King's Cross
Medical Boarding Centre
Ninewells
Perth Royal Infirmary
Ross Hall
Royal Aberdeen Children's
Royal Infirmary of Edinburgh
Stracathro
Western General
9 anonymous hospitals in the Highlands

WALES

Abergele
Aberystwyth Geriatric Unit
Amman Valley
Bala Health Centre
Barry
Brecon War Memorial
Bridgend General
Bron y Garth
Bronglais General
Bryn Beryl
Caerphilly District Miner's
Cardiff Royal Infirmary
Cardigan & District Memorial
Cefn Coed
Chepstow Community
Chirk Community
Clydach War Memorial
Colwyn Bay Community
County
Deeside Community
Denbigh Community
Dewi Sant
Dolgellau and Barmouth District
East Glamorgan General
Eryri
Ffestiniog Memorial
Glan Clwyd
Gorseinon
Gwynedd
H M Stanley
Holywell Community
Llandough
Llandovery
Llandrindod Wells
Llandudno General
Llanidloes War Memorial
Machynlleth
Mold Community
Montgomery County Infirmary
Morriston
Neath General
Nevill Hall
Newport Chest Clinic
Penrhos
Port Talbot
Prince Charles
Prince of Wales
Prince Philip (Llanelli)
Princess of Wales
Royal Alexandra (Rhyl)
Royal Gwent
Ruthin Cottage Community
Singleton
St. Woolo's
Tenby Cottage
Tywyn & District War Memorial
University Hospital of Wales
Vauxhall Orthopaedic Clinic
Velindre
Victoria Memorial
West Wales General
Withybush General
Wrexham Maelor
Yale

APPENDIX B DATA REQUESTED

(Essential data are highlighted)

1. Measurements of entrance surface dose per radiograph

Date …….		Hospital ……	
		X-ray room ……...	
Patient data			
Sex M / F		Weight ……..	
Age ……		Height* ……..	
		Thickness* ……	
Examination data			
Type of examination ……			
Projection ……			
Data for each radiograph			
Entrance surface dose	……... mGy		
FFD	……. cm	AEC used	Yes / No
Tube voltage	…… kV	Film size	……..cm x cm
Exposure setting	…….. mAs	Film diagnostic?	Yes / No
Equipment data			
Generator waveform	……...	Film make	…….
Total tube filtration	…... mm Al	Film type	…….
Antiscatter grid: - ratio	……	Intensifying screen make	…….
- strips/cm	……	Intensifying screen type	…….
- carbon fibre covers	Yes / No	Film/screen speed class	…….
- fibre spacers	Yes / No	Cassette with carbon fibre cover	Yes /No
Table top material	……	CR[#] make	……..
Table top Al equivalence	.....mm Al	CR[#] type	…….

* **For children**, it is essential that either the thickness of the body part being x-rayed **or** both the height and weight of the patient, be provided**.**

[#] CR = computed radiography (photostimulable phosphor)

DATA REQUESTED

(Essential data are highlighted)

2. Measurements of dose-area product per examination or procedure

Date …….		Hospital ……	
		X-ray room ……	
Patient data			
Sex M / F		Weight ……..kg	or small/medium/large
Age ……		Height* ……	
Examination data			
Type of examination	……		
Total dose-area product	……Gy cm^2		
Degree of difficulty+	Easy/Average/Difficult		
Radiography data			
No. of exposures (not necessarily no. of images) using:-			
Screen/film	……		
Computed radiography	……		
Photofluorography (eg. 100 mm camera)	……		
Digital spot imaging (not DSA)	……		
Digital subtraction angiography (DSA)	……		
Rapid film changer (eg. Puck, AOT)	…….		
Tube voltage range	…….. - …….. kV		
Fluoroscopy data			
Fluoroscopy time	……. Secs	AERC used?	Yes / No
Cine time	……. Secs	Last image hold?	Yes / No
Tube voltage range	……... - …….. kV	Pulsed fluoro.?	Yes / No
Tube current range	…….. - …….. mA		
Equipment data			
Generator waveform	……	Film make	……
Total tube filtration	…… mm Al	Film type	……
Antiscatter grid: - ratio	……	Intensifying screen make	. ……...
- strips/cm	……	Intensifying screen type	……
- carbon fibre covers	Yes / No	Film/screen speed class	……
- fibre spacers	Yes / No	Cassette with carbon	
Image intensifier FOV	……cm	fibre cover	Yes /No
Table top material	……	CR# make	.. ……
Table top Al equivalence	…… . . . mm Al	CR# type	……

* **For children**, it is essential that the height and weight of the patient, be provided**.**

+ Incomplete examinations should be excluded.

CR = computed radiography

APPENDIX C FILM-SCREEN SPEED CLASSES

Screen Manufacturer	Type	Film Manufacturer	Type	Speed class
Agfa	C2 Blue	Agfa	Curix Blue HC-SL	200
Agfa	Curix Blue 400HC	Agfa	Curix Blue HC-SL	400
Agfa	Curix Blue 400HC	Fuji	New RX	400
Agfa	Curix Blue 800HC	Agfa	Curix Blue HC-S Plus	700
Agfa	Curix Blue 800HC	Agfa	Curix Blue HC-SL	700
Agfa	Curix MR400	Agfa	Curix RP1L	300*
Agfa	Curix MR400	Agfa	Curix RP1	300*
Agfa	Curix Ortho Fast	Agfa	Curix Ortho HTL	700
Agfa	Curix Ortho Medium	Agfa	Curix Ortho HTL	200
Agfa	Curix Ortho Regular	Agfa	Curix Ortho HTG	400
Agfa	Curix Ortho Regular	Agfa	Curix Ortho HTL	400
Agfa	Curix Ortho Regular	Agfa	Curix Ortho HTL Plus	400
Agfa	Curix Ortho Regular	Agfa	Curix Ortho HTU	400
Agfa	Curix Ortho Regular	Konica	MGSR	400
Agfa	Curix Special	Agfa	Curix RP1	200
Du Pont	Quanta Detail	Du Pont	Cronex 10S	50
Du Pont	Quanta Fast Detail	Du Pont	Cronex 10	200
Du Pont	Quanta Fast Detail	Du Pont	Cronex 10S	200
Du Pont	Quanta Rapid	Du Pont	Cronex 10L	400
Du Pont	Quanta Super Rapid	Du Pont	Cronex 10S	600
Du Pont	Quanta 3	Du Pont	Cronex 10S	250*
Du Pont	Ultravision Fast Detail	Du Pont	Ultravision L	200
Du Pont	Ultravision Rapid	Du Pont	Ultravision G	400
Du Pont	Ultravision Rapid	Du Pont	Ultravision L	400
Du Pont	Ultravision Super Rapid	Du Pont	Ultravision L	800
Fuji	G3	Fuji	Super HRL	150
Fuji	G6	Fuji	Super HRG	300
Fuji	G8	Agfa	Curix Ortho HTU	400
Fuji	G8	Fuji	HRL/HRG	400
Fuji	G8	Fuji	Super HRL	400
Imation/3M	Trimax T2	Imation/3M	XDA Plus	100
Imation/3M	Trimax T16	Imation/3M	XLA Plus	600
Imation/3M	Trimax T6	Fuji	Super HRG	300
Imation/3M	Trimax T6	Imation/3M	XDA Plus	300
Imation/3M	Trimax T8	Fuji	HRL	400
Imation/3M	Trimax T8	Imation/3M	XDA Plus	400
Imation/3M	Trimax T8	Imation/3M	XLA Plus	400
Imation/3M	Trimax T8	Imation/3M	XDA	400

Kodak	Insight HC	Kodak	Insight	320
Kodak	Lanex Fast	Fuji	Super HRL	600
Kodak	Lanex Fast	Kodak	T-Mat G	600
Kodak	Lanex Fast	Kodak	T-Mat L	600
Kodak	Lanex Medium	Kodak	T-Mat L	250
Kodak	Lanex Regular	Agfa	Curix Ortho HTU	400
Kodak	Lanex Regular	Imation/3M	XDA Plus	400
Kodak	Lanex Regular	Kodak	T-Mat G	400
Kodak	Lanex Regular	Kodak	T-Mat L	400
Kodak	Lanex Regular	Konica	MGSR	400
Kodak	Xomat Regular	Kodak	Xomat S	200
Konica	KM	Konica	MGSR	300

* Indicates independent measurement of speed, rather than manufacturer's speed class. See British Journal of Radiology, April 1993, pp318 and 334.