Doses to Patients arising from Dental X-ray Examinations in the UK, 2002–2004

A Review of Dental X-ray Protection Service Data

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ABSTRACT

The Dental X-ray Protection Service, DXPS, is part of the Radiation Protection Division of the Health Protection Agency, and is based at the Occupational Services Department in Leeds. DXPS has provided radiation protection advisory and technical services to dentists for over 30 years. Previous analyses of the results of routine patient dose measurements have provided data on the ranges of doses delivered during x-ray examinations in the UK, and allowed the derivation of third quartile dose values. A previous DXPS study, published in the British Dental Journal in 1999[1], recommended the adoption of reference doses, based on third quartile doses, for the two most common types of dental radiograph.

The most frequently undertaken dental x-ray examination is the intra oral radiograph. The reference dose for intra oral radiography recommended on the basis of the 1999 paper was 4 mGy, for an adult mandibular molar radiograph. The 1999 paper also recommended that the reference dose for panoramic radiography should be 65 mGy mm for a standard adult radiograph, and both these values were subsequently adopted as remedial levels in IPEM Report 77 and its recently updated version, IPEM Report 91[2].

Over the course of time, there has been a significant and continual reduction in patient dose for intra oral radiography, and this trend is evident in the data presented in this paper. The results of this study, which cover DXPS's results of x-ray set assessments over the calendar years 2002 to 2004, demonstrate that the third quartile dose for intra oral radiography has now fallen to 2.4 mGy. For panoramic radiography a much slighter reduction is apparent, with the third quartile dose now being 60 mGy mm. This paper examines the underlying causes for the above results and speculates on the scope for further dose reduction in the future.

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1 INTRODUCTION

The Dental X-ray Protection Service (DXPS) has provided radiation protection services to dentists in the UK since its inception in the 1970s. From the outset specially designed postal test packs have been used to undertake the remote assessment of the performance of intra oral and panoramic (or orthopantomographic, OPG) x-ray sets. These are the most common types of dental x-ray equipment in the UK, with approximately 10 million intra oral examinations (each comprising two bitewing radiographs) and 3 million panoramic examinations being carried out annually[3]. Cephalometric radiography is another well-established radiographic technique, although the numbers of x-ray sets in use in the UK is much lower than either intra oral or panoramic sets. Of interest is the recent advent of dedicated dental CT x-ray equipment in the UK. It is likely that these will only be used at specialist referral centres for orthodontic work; hence their numbers should remain relatively low.

One of the strategic goals of the Health Protection Agency's Radiation Protection Division (RPD) is to monitor the radiation exposure of patients arising from medical and dental examinations, and to recommend national reference doses for specific x-ray examinations based on analysis of the National Patient Dose Database (NPDD). This work has been carried out since the 1990s. Reference doses have been set at around the third quartile value of the typical doses used for an average adult patient at each hospital or practice and act as a means of identifying those radiographic practices that are using unusually high doses and are thus most in need of corrective action (assuming in each case that the high patient dose is not clinically justifiable). The RPD-recommended 'national reference doses' have become a major source of input to the Department of Health Working Party that sets and periodically reviews national diagnostic reference levels (NDRLs). Nowadays, the Ionising Radiation (Medical Exposure) Regulations 2000 require employers performing diagnostic examinations to adopt and implement their own 'local' DRLs as an aid to their efforts to adequately restrict patient dose, having due regard to 'national DRLs' where these have been formally adopted and promulgated by DH. The latest review of the medical exposure of the UK population was undertaken in 2000 and the results reported in NRPB report W-14[4]. At that time, no dental radiography doses were included in the NPDD and so the then Technical Manager of DXPS undertook an independent analysis of patient doses based on assessment data collected by DXPS over the three-year period 1995 to 1998. The results were published in the British Dental Journal in 1999, and included recommended reference doses for intra oral and panoramic radiography.

The NPDD now contains patient dose data for intra-oral and panoramic dental radiography contributed by DXPS and other medical physicists who act as Radiation Protection Advisers for dental practices. The 2005 review of the NPDD (to be published shortly)[5] will propose new national reference doses for intra-oral and panoramic dental radiography based on this data. This report summarises the results of the most recent analysis of DXPS assessment data covering the period 2002 to 2004, which was recently submitted for inclusion in the 2005 review, and which represents the largest contribution of dental radiography data to the NPDD. Patient doses arising from cephalometric examinations are not included as systematic records of this data have only recently commenced.

The analysis of DXPS data indicates a significant reduction in the apparent third quartile dose for intra oral radiographs. No such reduction is apparent in the third quartile dose for panoramic radiographs. The underlying causes for these observations, and their implications, are discussed in this report.

2 ASSESSMENT METHODS

2.1 Intra oral x-ray sets

The intra oral postal test pack enables the assessment of all relevant characteristics of the x-ray tubehead, the performance of the timer unit, and measurement of the patient entrance dose corresponding to the exposure settings selected by the operator for an adult mandibular molar radiograph. This is used together with written information supplied by the user to evaluate the performance of the x-ray set against relevant standards, and hence to determine the acceptability of the x-ray set in question. The method of use of the test packs is illustrated below.

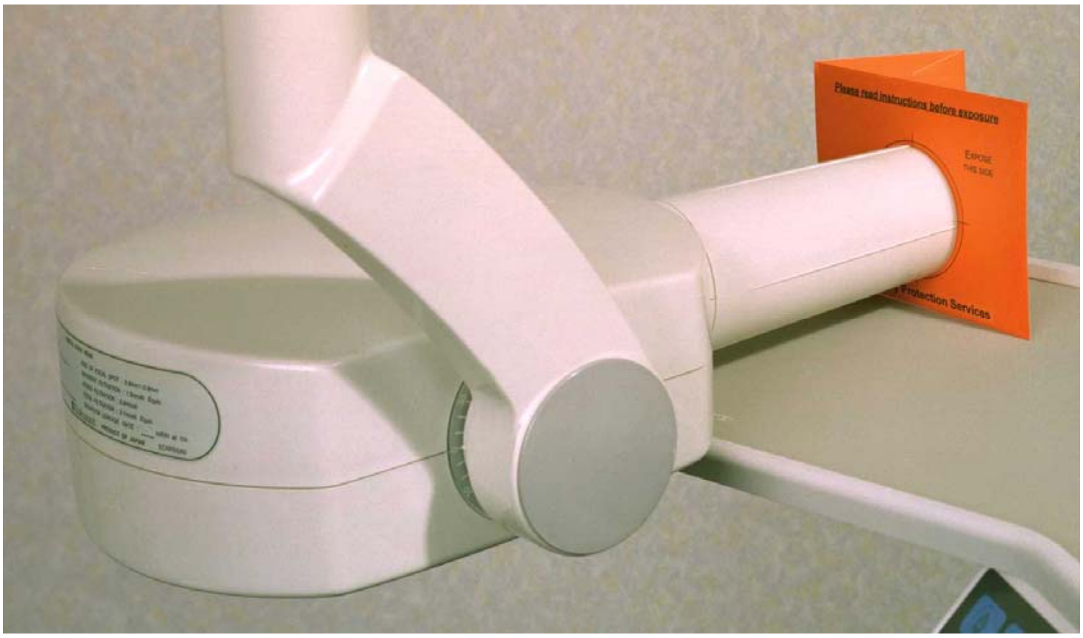

Figure 1 Showing use of intra oral test pack

The dose quantity measured by the test pack is the absorbed dose to air at the end of the spacer/director cone, in mGy. For intra oral radiographs, the cone is in either in contact with or very close to the skin of the patient, and hence this is essentially a measurement of patient entrance dose. It should be noted that this differs from the quantity entrance surface dose commonly used in general medical radiography by not including radiation backscattered from the patient[6].

2.2 Panoramic x-ray sets

Similarly to the method used for intra oral sets, the panoramic assessment method relies on the test pack to provide information on the operating parameters of the x-ray tubehead, together with further details provided on a questionnaire. Use of the panoramic test pack is illustrated in Figure 2 below.

Figure 2 Showing use of panoramic test pack

For panoramic radiography it is far more difficult to obtain a measurement that gives a direct indication of patient dose, due to the design and mode of operation of the equipment. In panoramic radiography a vertically collimated x-ray beam, typically 5.0 mm wide by 130 mm high, is directed around the patient's head from one side of the jaw to the other, while the imaging cassette rotates and traverses the patient's head on the opposite side. For this reason the accepted convention was to use the quantity 'dose width product' (DWP) as an indicator of patient exposure. This is the peak dose in the centre of the beam, measured at the position of the secondary collimator, multiplied by the beam width at that point, and has the units of mGy mm. The position of the secondary collimator in relation to the film cassette and the patient positioning aids can be seen in Figure 2, where it is covered by the RPD test pack.

DWP was the quantity in which the results of the dose analysis reported in the 1999 BDJ paper was expressed. However, as stated in that paper, a superior indicator of patient dose would be provided by the quantity dose-area product (DAP), which can be expressed most simply as the DWP multiplied by the beam height. DAP has the units mGy cm^2. It has been suggested as a suitable quantity for expressing DRLs for panoramic dental radiography in IPEM Report 88[5] and is used to set 'remedial levels' for patient doses from panoramic dental radiography in IPEM Report 91[2]. However, DAP has not yet been universally adopted as the preferred quantity for assessing the performance of panoramic equipment because a standardised method of measurement of DAP for panoramic equipment has yet to be proposed. To this end, DXPS is investigating the development of a suitable method of measuring DAP, based on the use of the RPD postal test pack. Once this work is complete it is intended to publish a short paper describing the method and proposing the adoption of DAP as the quantity for expressing reference doses for panoramic dental radiography.

3 RESULTS

3.1 Compilation of data

The results of all assessments of carried out in the period 1 January 2002 to 31 December 2004 were collated in separate databases, one for intra oral and one for panoramic x-ray sets. The Guidance Notes for Dental Practitioners of the Safe Use of X-ray Equipment[7] (the 'Dental GNs,' available for free download from www.hpa.org.uk/radiation/publications/misc_publications/dental_guidance_notes.htm) state that dental x-ray equipment should be tested at least once every three years, and the above interval was chosen to represent the most complete and up-to-date set of results covering a three-year period. Following the approach taken in the 1999 study, the raw data were subjected to a process of selection so as to filter out those results least representative of x-ray equipment in current clinical use. A significant proportion of x-ray set users opt to have their equipment assessed on an annual basis, and where an x-ray set was assessed more than once during the period, only the latest results were retained. Assessments relating to critical examinations of newly-installed or modified equipment were likewise excluded as the results may not be representative of the actual clinical use of equipment. Finally, results representing extremely high or low values of the various assessed parameters were individually verified to validate their inclusion in the data.

3.2 Patient doses

The data resulting from the process of selection described above was transposed into an MS Excel spreadsheet to facilitate the analysis. This generally included, for each parameter, the determination of the range, third quartile and mean values. It also permitted the easy production of histograms to depict the frequency distributions of patient dose and relevant x-ray tubehead characteristics graphically. The results for patient entrance dose for an intra oral adult mandibular molar radiograph are shown in Table 1, where they are compared to the values derived in the 1999 study.

TABLE 1 Comparison of intra oral dose data

Parameter	Assessed Value	
	2005 study	1999 study
Highest dose, mGy	30.0	45.7
Lowest dose, mGy	0.05	0.14
Third quartile dose, mGy	2.4	3.9
Mean dose, mGy	1.9	3.3
Sample size	4006	6344

Note: the difference in sample sizes is due to variations in workload over the two periods of study.

Comparison of the mean and third quartile dose values suggests that a substantial reduction in patient doses arising from intra oral radiography has occurred in the six years separating the two studies. However, both studies show a very large range of values, with a factor of around 600 between the lowest and highest doses in the 2005 study, and around 300 in the 1999 study. These ranges are far larger than should be apparent from a consideration of the performance of different types of x-ray set and imaging methods used, and point to a wide variation in the quality of radiographic practice in dentistry. Histograms depicting the distribution in the values of measured patient entrance doses in the two studies are given in Figures 3 and 4, below.

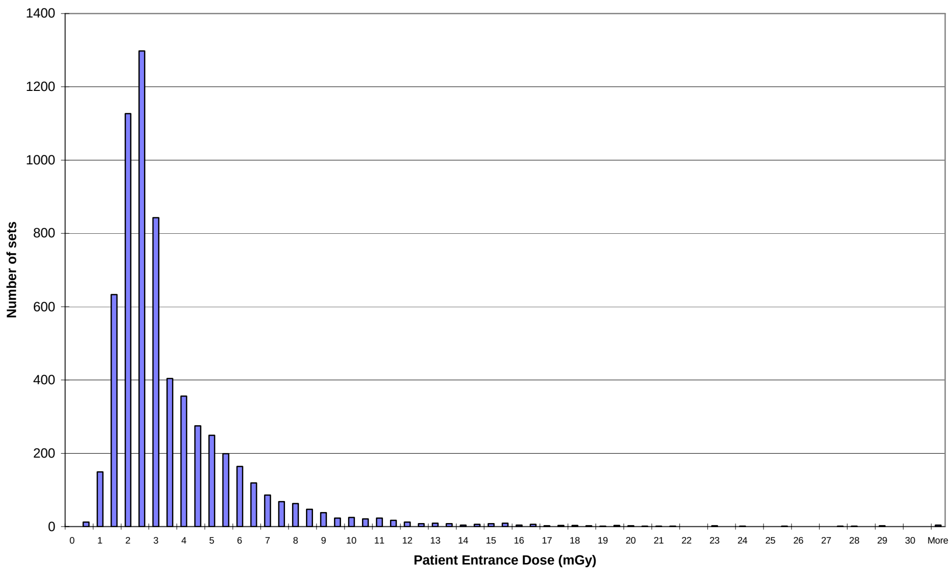

Figure 3 Distribution of patient entrance doses for intra oral radiographs in the 1999 study

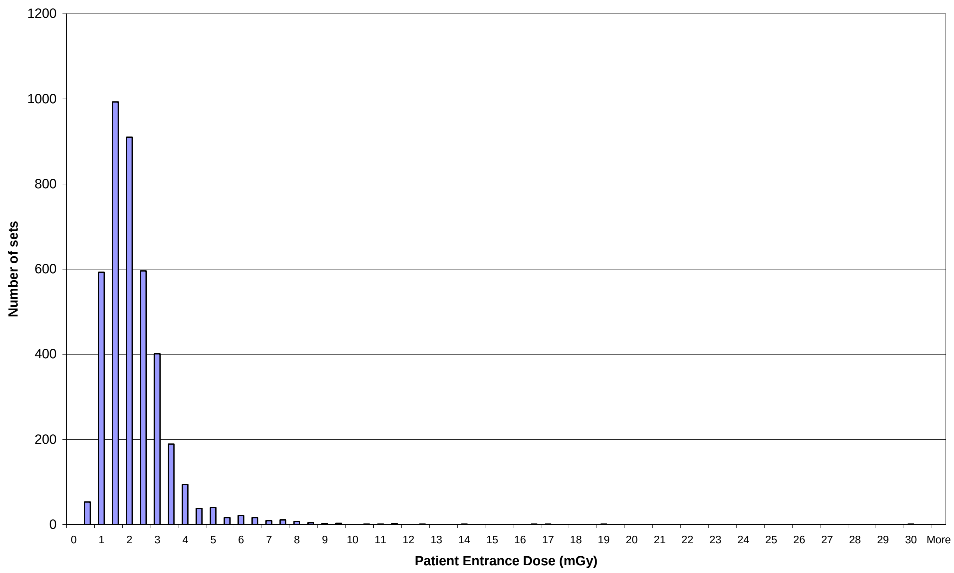

Figure 4 Distribution of patient entrance doses for intra oral radiographs in the 2005 study

The results for the dose-width product (DWP) and dose-area product (DAP) for a panoramic dental examination are likewise shown in Table 2, where they are compared to the values derived in the 1999 BDJ paper.

TABLE 2 Comparison of panoramic dose data

Parameter	Assessed Value	
	2005 study	1999 study
Highest DWP, mGy mm	271	328
Lowest DWP, mGy mm	11.4	1.7
Third quartile DWP, mGy mm	59.7	66.7
Mean DWP, mGy mm	51.8	57.4
Highest DAP, mGy cm^2	444	567
Lowest DAP, mGy cm^2	14.6	2.1
Third quartile DAP, mGy cm^2	78.1	91.6
Mean DAP, mGy cm^2	68.2	76.8
Sample size	1719	387

Note: the relatively small size of the sample in the 1999 study is due to the fact that panoramic data were only recorded systematically from July 1997 onwards.

Table 2 suggests that patient doses arising from panoramic radiography have also reduced during the last few years, though not to such an extent as is evident with intra oral radiography. Again, both studies indicate a range of values in both DWP and DAP, beyond that which may reasonably be explained by differences in equipment. Histograms depicting the distribution in the values of DWP and DAP in the two studies are given in Figures 5 to 8, below.

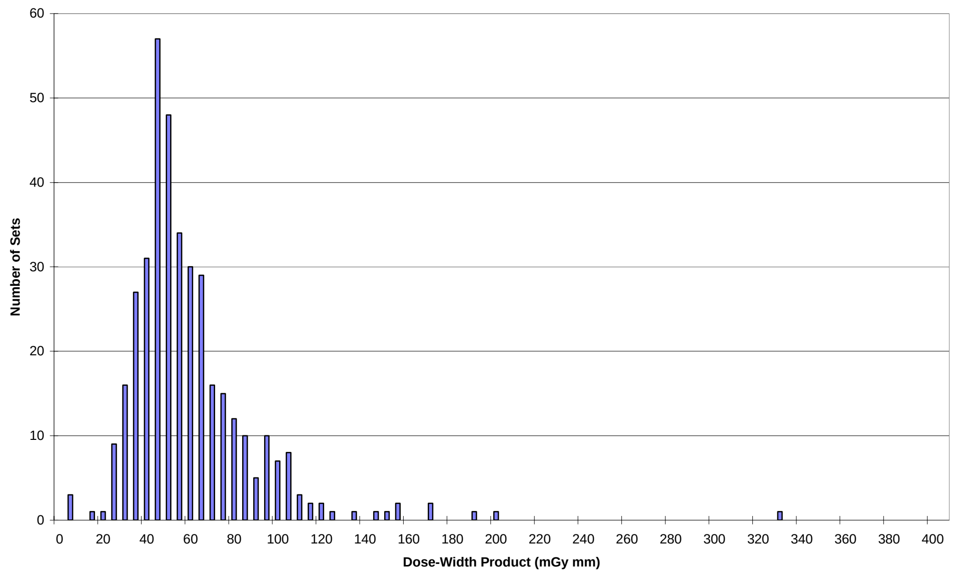

Figure 5 Showing distribution of DWP values in panoramic x-ray sets in the 1999 study

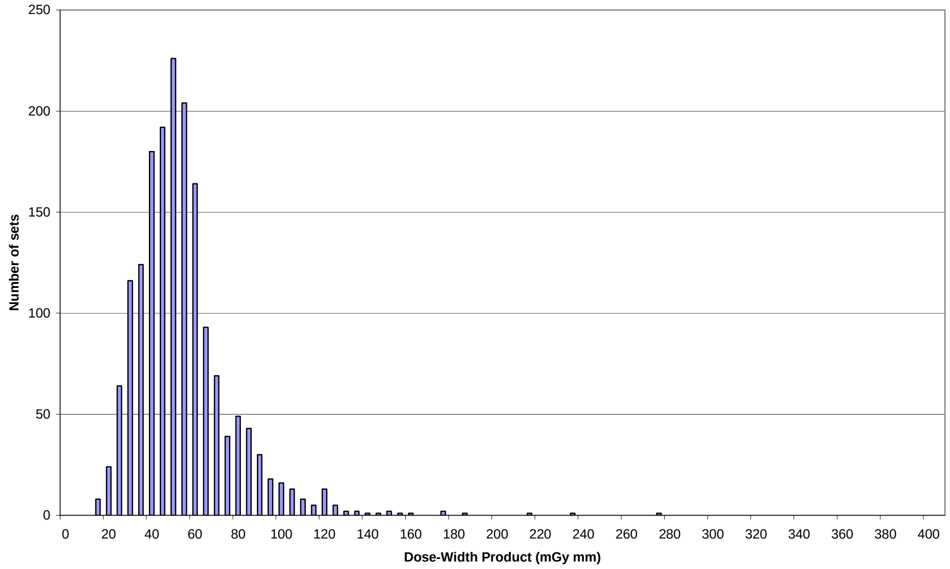

Figure 6 Showing distribution of DWP values in panoramic x-ray sets in the 2005 study

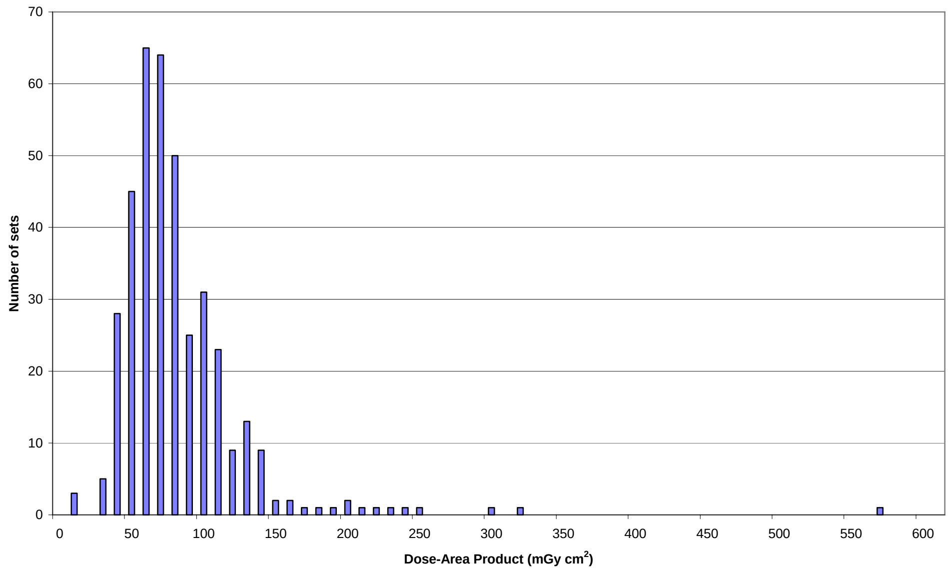

Figure 7 Showing distribution of DAP values in panoramic x-ray sets in the 1999 study

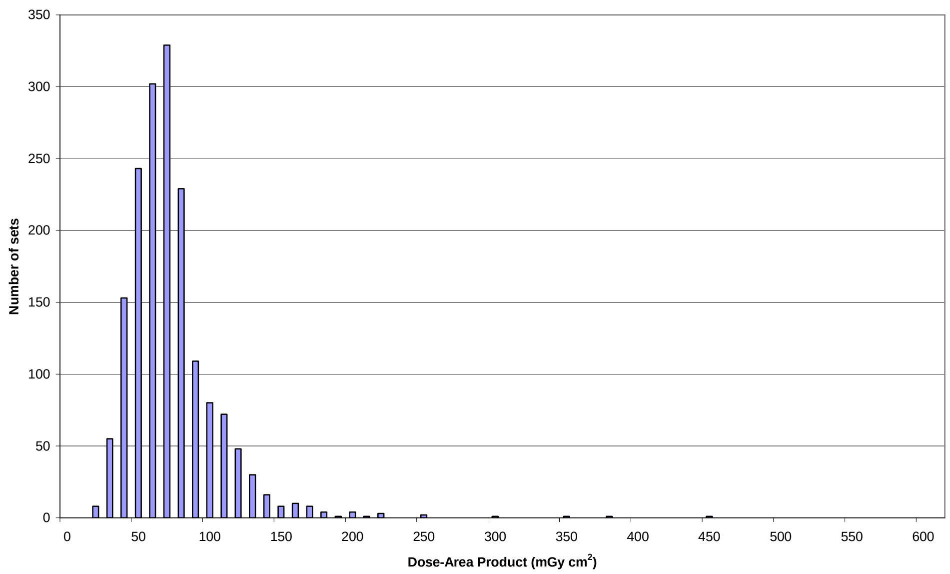

Figure 8 Showing distribution of DAP values in panoramic x-ray sets in the 2005 study

3.3 Discussion of results

3.3.1 Intra oral

The results of the current study show a significant reduction in the third quartile dose compared to that published in the 1999 BDJ paper, from 3.9 mGy to 2.4 mGy. This 40% reduction in only 6 years is significant and if representative of the national picture, effectively renders the reference dose of 4 mGy that was recommended by RPD in 1999 obsolete. Personal communications between the authors and another significant contributor of dental data to the NPDD suggests that this is indeed the case. It is, therefore, anticipated that the 2005 review of the NPDD will recommend that a lower figure be adopted as the national reference dose. Investigation of the results of DXPS assessments provides a clear illustration of the underlying trends in dental x-radiography over recent years that have lead to the above result. The essential factors are as follows:

a A significant reduction in the proportion of x-ray sets of that are of older manufacture and operate at low kVs; and

b An attendant significant increase in the proportion of dentists using film of a faster speed rating (speed groups E or F), together with an increasing use of digital imaging systems.

These are discussed in turn in the following section.

3.3.1.1 Influence of operating potential (kV)

The Dental GNs recommend that new intra oral x-ray sets should operate in the range 60 kV to 70 kV, while any sets operating below 50 kV should be replaced as soon as reasonably practicable. Sets assessed as operating below 45 kV should be immediately removed from use.

The 1999 study clearly illustrated the influence of operating potential on the patient entrance dose. If all other relevant exposure factors remain the same, an x-ray set operating at 70 kV will produce a clinically ideal radiograph at 50% of the dose required at 50 kV. The 1999 study demonstrated that x-ray sets in use at the time effectively fell into two groups; one in which the assessed kV fell into the range 45 to 55 kV, and another where the kVs ranged from 60 to 70 kV. Together, these two groupings accounted for 83% of all the sets in the sample. Comparison of the data in the studies clearly shows a trend over the years towards the use of x-ray sets operating at higher kVs, with the benefit of lower attendant patient doses. By the time of the present study, the lower kV subset has almost disappeared. This is summarised in Table 3 and Figures 9 and 10.

TABLE 3 Distribution of kVs in studies of patient doses from intra oral x-ray sets

Reference	Percentage of total sample in kV range		Third quartile dose, mGy
	45-55 kV	60-70 kV	
Radiation Protection Theory and Practice, Institute of Physics 1989	Not stated	21	6.5
British Dental Journal, 1999	34	49	3.9
2005 study of DXPS data	8	63	2.4

The influence of operating potential on patient dose can be clearly seen in Tables 4 and 5, in the following section.

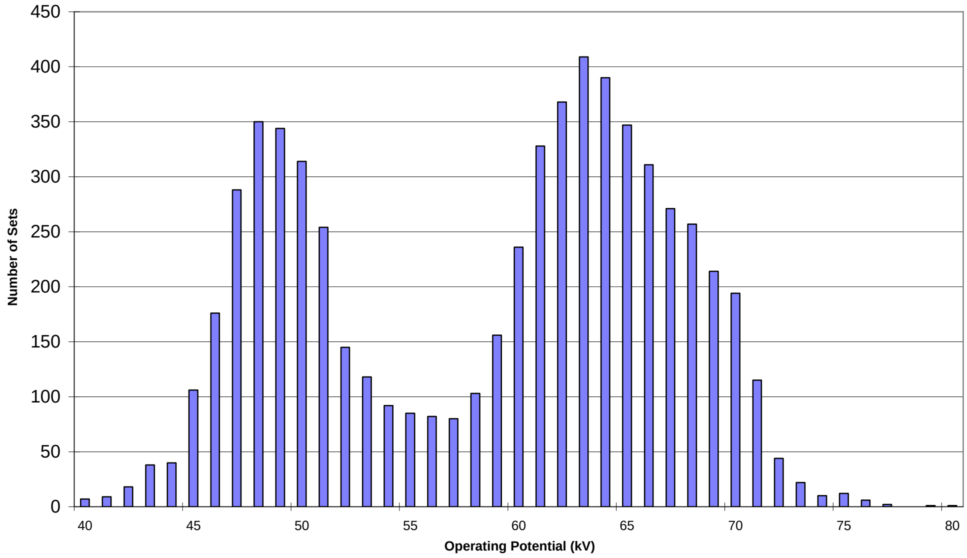

Figure 9 Showing distribution of operating potentials in intra oral x-ray sets in the 1999 study

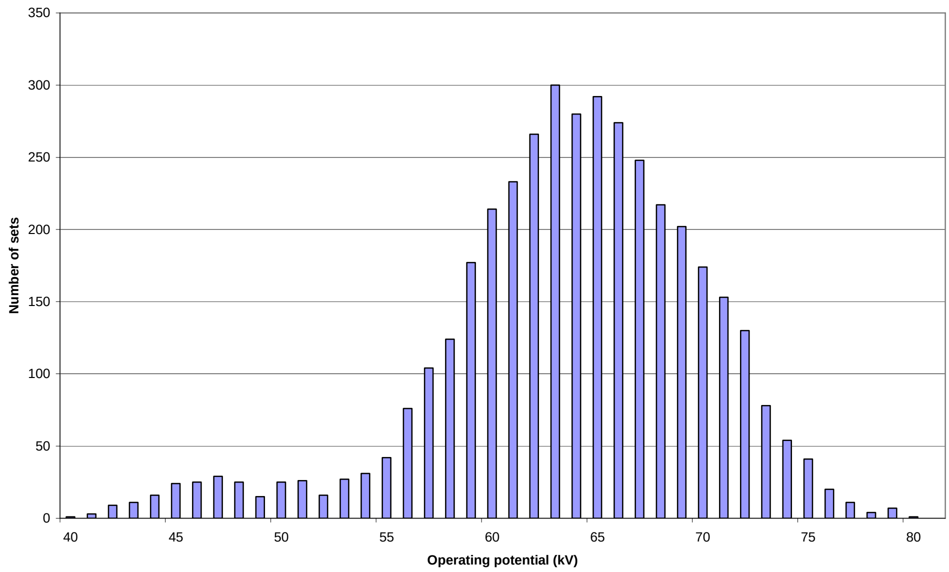

Figure 10 Showing distribution of operating potentials in intra oral x-ray sets in the 2005 study

3.3.1.2 Influence of imaging system

The Dental GNs recommend that E-speed film (or faster) be used in preference to D-speed film, due to the resultant saving in patient dose. Again, if all other exposure factors are unchanged, use of E- or F-speed film will achieve a reduction in patient dose relative to D-speed film, of around 45% and 60%, respectively. It should be noted that there is scope for further dose reduction through the use of digital systems, perhaps by as much as 80% compared to D-speed film. However, the full dose reduction benefits of switching to the use of a digital system can only be realised if it is to be used with an x-ray set of an appropriate modern design. Furthermore, digital systems commonly provide software enabling the image displayed on the computer screen to be adjusted to achieve optimum diagnostic quality over a much wider range of exposure settings than is possible with film-based radiography. DXPS has observed that users of digital systems often rely on the software to produce optimum quality images while failing to make use of the dose reduction potential afforded by the equipment. It would appear that this may be due to a generally poor level of understanding of the technical issues involved in the use of digital imaging systems in dental radiography. DXPS intends to raise this issue with both the suppliers and users of digital systems.

The 1999 BDJ paper indicated that 25% of dentists reported using E-speed film or faster. In the current study, this proportion has risen to 73%. The move away from the use of D-speed film has contributed significantly to the reduction in the third quartile value of patient entrance dose. The influences of both the kV and the speed of the imaging system used on patient entrance dose, are illustrated in Tables 4 and 5 below.

The most recent DXPS data (covering the period December 2005 to January 2007) indicates that this trend is continuing, with the proportions of x-ray sets used with speed group D, E and F film and digital imaging systems being around 16%, 45%, 17% and 22%, respectively. The influence on patient dose of the increasingly common use of films of speed groups E and F, and of digital systems in particular, will be the subject of more detailed analysis once sufficient data has been collected.

TABLE 4 Influence of kV and film speed on patient dose for intra oral x-ray sets – 1999 study

Description of x-ray set	Number of x-ray sets in sample	Mean dose in sample, mGy	Third quartile dose in sample, mGy
All x-ray sets	6344	3.3	3.9
45-55 kV	2175	5.0	5.9
45-55 kV using E-speed film (or faster, incl. digital)	471	4.1	5.1
60-70 kV	3105	2.2	2.5
60-70 kV using E-speed film (or faster, incl. digital)	839	1.8	2.1

TABLE 5 Influence of kV and film speed on patient dose for intra oral x-ray sets – 2005 study

Description of x-ray set	Number of x-ray sets in sample	Mean dose in sample, mGy	Third quartile dose in sample, mGy
All x-ray sets	4006	1.9	2.4
45-55 kV	262	3.1	3.6
45-55 kV using E-speed film (or faster, incl. digital)	201	2.9	3.5
60-70 kV	2508	1.8	2.2
60-70 kV using E-speed film (or faster, incl. digital)	682	1.8	2.1

3.3.1.3 Other factors

Other factors that strongly influence patient dose include the total filtration and focal spot to skin distance (FSD); both of which have altered significantly over time as x-ray set designs have developed.

The oldest sets assessed by DXPS may, in addition to operating at low kVs, be fitted with short spacer/director 'cones' providing a FSD of around 100 mm. This is in contrast to modern equipment which, in line with the Dental GNs, generally has a FSD of 200 mm or 300 mm. The patient dose resulting from use of an intra oral x-ray set with a 100 mm cone will be 30% higher than if a 200 mm cone is used, for exposure factors giving equivalent radiographic densities on the film. The influence of filtration is even more marked, with an x-ray tubehead incorporating a total filtration equivalent to 1.5 mm of aluminium producing a patient dose more than 50% higher than an equivalent set fitted with 2.5 mm of aluminium. In reality, the older sets tend to be associated with the use of slower D-speed film, further contributing to higher patient doses. Nevertheless, the numbers of sets with such short cones or low values of total filtration are now very low, with the result that the kV and imaging system 'speed' are the two factors that most strongly influence the third quartile dose.

3.3.2 Panoramic

Compared to the large downward shift in patient dose observed with intra oral x-ray sets, the reduction in the third quartile values for DWP and DAP for panoramic sets is less striking when compared to the results of the 1999 study. A comparison of the parameters from which the values of DWP or DAP are derived for each panoramic x-ray set assessed, is provided in the table below.

TABLE 6 Comparison of results for panoramic x-ray sets

Parameter	Assessed Value	
	1999 study	2005 study
Third quartile operating potential (kV)	78.1	77.6
Mean operating potential (kV)	74.8	73.5
Third quartile dose at secondary collimator (mGy)	24.0	21.5
Mean dose at secondary collimator (mGy)	19.1	17.7
Third quartile beam width (mm)	4.0	3.5
Mean beam width (mm)	3.1	3.0
Third quartile beam height (mm)	140	134
Mean beam height (mm)	133	131
Third quartile DAP (mGy cm^2)	92	78
Mean DAP (mGy cm^2)	77	68
Third quartile DWP (mGy mm)	67	59
Mean DWP (mGy mm)	51	52

The relatively small size of the sample in the 1999 study (387) compared to that in the 2005 study (1719) suggests caution should be exercised when attempting to identify trends in the data in Table 6. However, it is clear that, in contrast to intra oral radiography there has been no radical change in the characteristics of either the x-ray equipment or the imaging systems in panoramic radiography over the last few years. Consequently there has been no significant reduction in patient dose since the 1999 study. Modern intensifying screen and film combinations have speeds comparable to digital imaging systems for panoramic equipment, and it follows that the general trend towards a greater use of digital imaging technology in panoramic radiography will not provide an attendant reduction in patient dose. Depending on the results submitted to the NPDD by other contributors, it is considered unlikely that the 1999 reference dose in terms of DWP (65 mGy mm) will change significantly. Histograms depicting the distributions of DWP, DAP and assessed values of operating potential, beam width and beam height for the 1999 and 2005 studies, are provided below in Figures 11 to 16.

It should be noted that some of the digital panoramic models most recently introduced into the UK are configured by the manufacturer such that the DWP for a standard adult radiograph would exceed the reference dose recommended in 1999, which is to say that their widespread use would cause the third quartile dose to increase over time. This is obviously a matter for concern and DXPS is raising these issues with the UK agents of the relevant manufacturers with the aim of determining if it is possible to use lower exposure settings to produce images of clinically adequate diagnostic value. DXPS will continue to monitor the influence of the increasing use of digital panoramic equipment on patient dose, and to bring any issues of significance to the attention of manufacturers, suppliers and users.

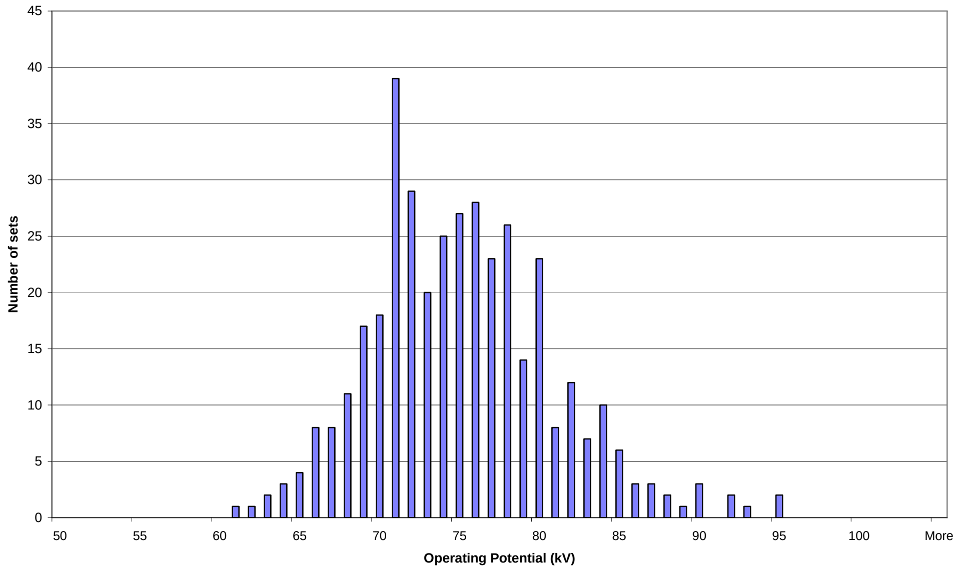

Figure 11 Showing distribution of operating potentials in panoramic x-ray sets in the 1999 study

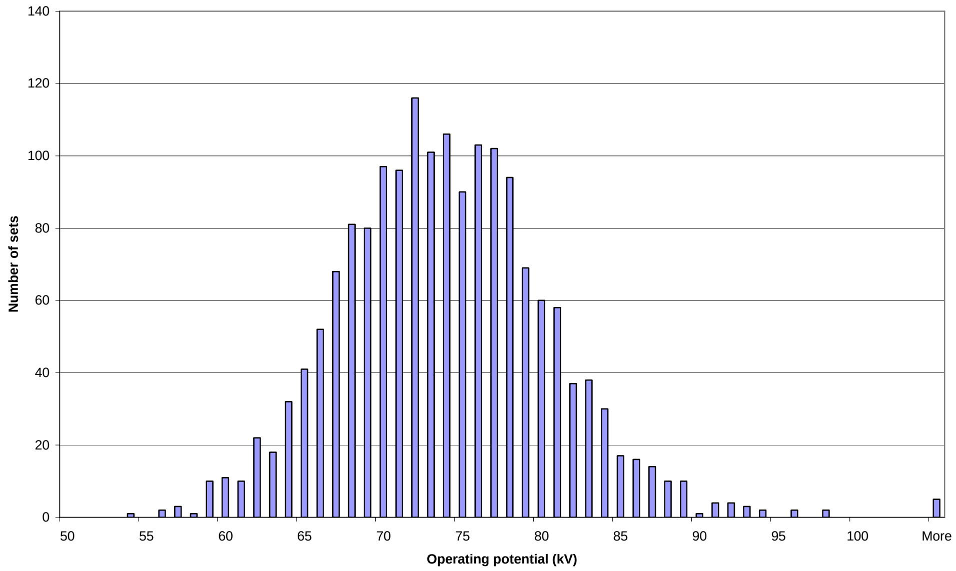

Figure 12 Showing distribution of operating potentials in panoramic x-ray sets in the 2005 study

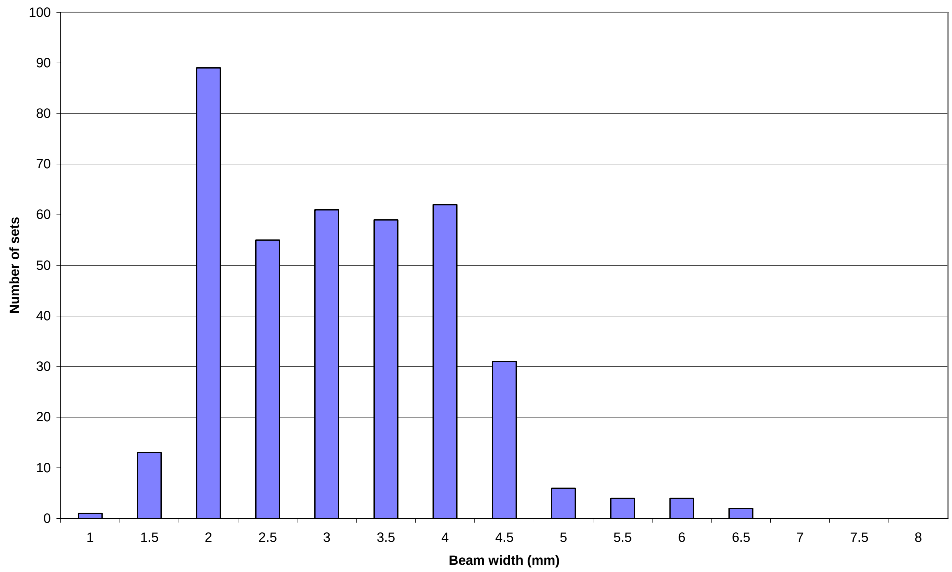

Figure 13 Showing distribution of beam width values in panoramic x-ray sets in the 1999 study

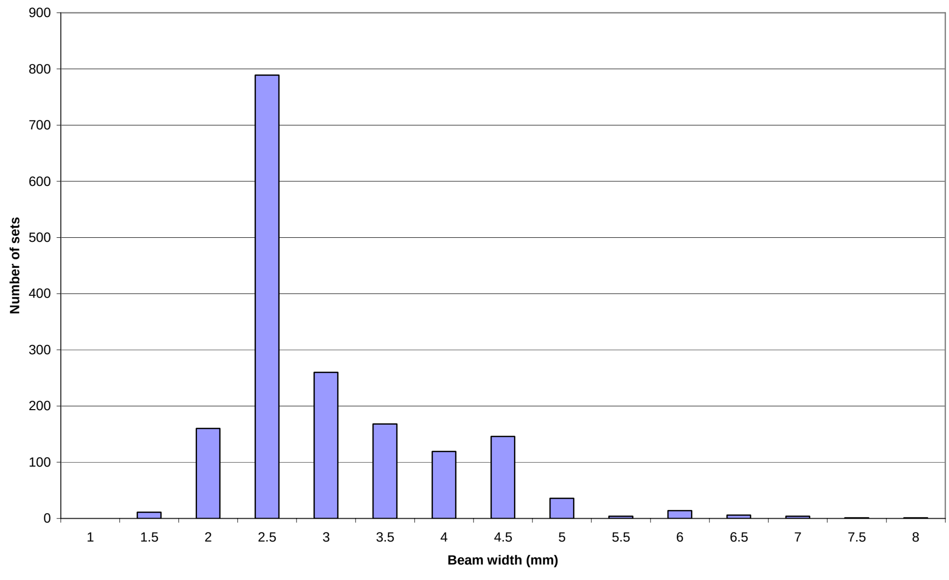

Figure 14 Showing distribution of beam width values in panoramic x-ray sets in the 2005 study

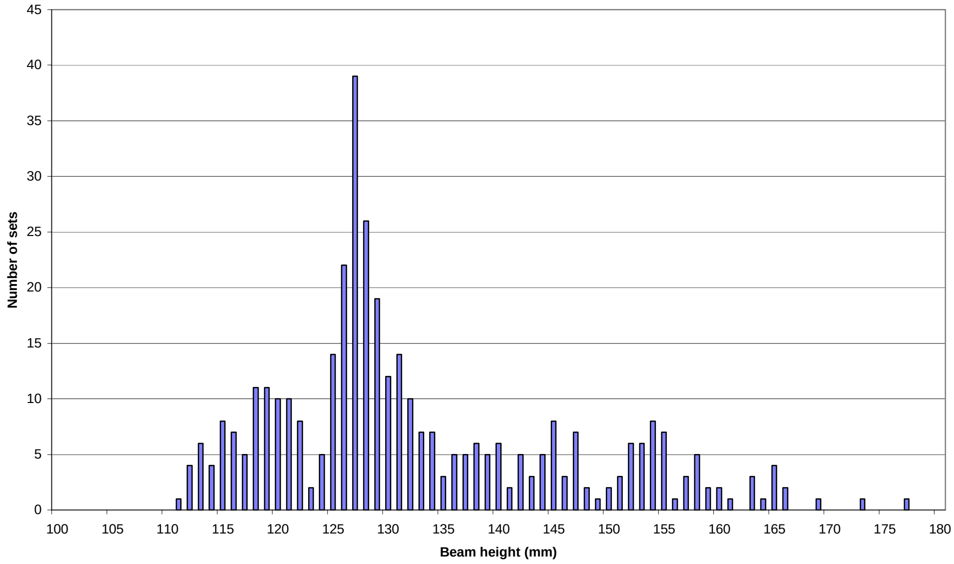

Figure 15 Showing distribution of beam height values in panoramic x-ray sets in the 1999 study

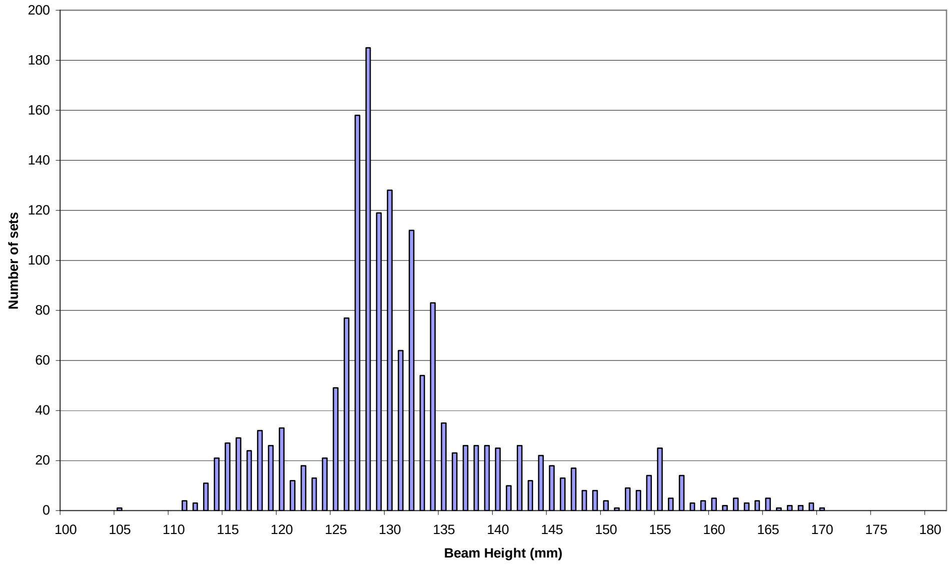

Figure 16 Showing distribution of beam height values in panoramic x-ray sets in the 2005 study

4 FUTURE WORK

4.1 Digital imaging systems

As discussed, the increasing use of digital intra oral image receptors makes possible further significant reductions in patient dose. DXPS undertakes frequent reviews of assessment results, and will continue to monitor the influence of this trend on patient dose. There is also a clear need to monitor the influence on patient doses arising from the increasing use of digital panoramic equipment, although for different reasons.

DXPS will continue to develop a dialogue with the manufacturers and suppliers of digital imaging systems to ensure that dentists and other staff involved with dental x-ray equipment are provided with sufficient information to enable them to make informed purchasing decisions regarding the capability of equipment to achieve the adequate restriction of patient dose. DXPS will also develop guidance for users of digital systems regarding the exposure settings appropriate for use in digital radiography, and an appropriate regime of quality assurance checks to maintain optimum imaging performance and hence, optimisation of patient dose.

4.2 Cephalometric radiography

DXPS intends to compile data on measurements representative of patient doses received during cephalometric radiography. This data will be subject to analysis and the results presented in a future report.

5 CONCLUSIONS

Analysis of the DXPS assessment results for intra oral x-ray sets described in this paper indicates a significant reduction in the third quartile value of patient entrance dose, from 3.9 mGy in 1999 to 2.4 mGy. The data discussed in this paper is fairly representative of the national picture and is likely to be the largest single contributor to the NPDD. It follows that the 2005 review of the NPDD, soon to be published, is likely to recommend the adoption of a revised national reference dose substantially less than 4 mGy.

It should be noted that there is plenty of scope for further reductions in patient doses resulting from intra oral radiography. Replacement of the few remaining low-kV sets will not impact on this significantly, but the continuing trend towards the use of faster speed film (speed groups E and F) will have a beneficial impact. The most significant potential influence, however, will be the extent to which the use of digital imaging systems becomes widespread.

While slight reductions in the third quartile values for DWP and DAP are apparent for panoramic x-ray equipment, it is unlikely that, when considered together with the other data in the NPDD, these will necessitate any substantial change to the current recommended national reference dose.

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