Techniques for measurement of dose width product in panoramic dental radiography

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ABSTRACT. Dose width product (DWP) is the quantity recommended for assessment of patient dose for panoramic dental radiography. It is the product of the absorbed dose in air in the X-ray beam integrated over an exposure cycle and the width of the beam, both measured at the receiving slit. A robust method for measuring the DWP is required in order to facilitate optimization of practices and enable comparison of dose levels at different centres. In this study, three techniques for measuring the DWP have been evaluated through comparison of results from 20 orthopantomographic units. These used a small in-beam semiconductor detector and X-ray film, a pencil ionization chamber and an array of thermoluminescent dosemeters (TLDs). The mean results obtained with the three techniques agreed within ±6%. The technique employing a pencil ionization chamber of the type used for dose assessment of CT scanners is the simplest and most reliable method. The in-beam detector and film method has larger errors both from positioning the radiation detector and from measurement of X-ray beam width, which should be the full width at half maximum obtained from a scan of the film optical density. The TLD array method was accurate, but more time consuming to carry out. The mean DWP for the units studied was 65 mGy mm and the mean dose–area product was 89 mGy cm^2. The DWP for 30% of the units tested exceeded the diagnostic reference dose of 65 mGy mm, recommended by the National Radiological Protection Board.

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Panoramic radiography is a technique used in dentistry to show the mandibular joints with the teeth laid out between them. The X-ray tube and film holder both rotate during the exposure. The film is exposed to a narrow X-ray beam through a secondary collimator slit, across which the film moves as the radiographic image is built up. The assessment of patient dose in panoramic radiography is difficult because of the dynamic nature of the imaging process and the narrow width of the X-ray beam. The dose quantity used is the product of the absorbed dose in air and the horizontal width of the beam, both measured at the front side of the secondary collimator slit, and integrated over a standard exposure cycle. This is referred to as the dose width product (DWP) with units of mGy mm. The DWP provides a measurement related to the total amount of radiation to which the patient is exposed. It can be derived either from the product of the peak dose at the centre of the X-ray beam and the width of the beam, or from an incremental summation of the dose across the beam. The aim of this study has been to compare and evaluate results obtained from different techniques available for measuring DWP.

As part of the National Radiological Protection Board (NRPB) dental X-ray protection service, Napier reported DWPs for 387 panoramic dental X-ray sets derived from a technique that employed film to assess both dose and beam width [1]. Based on results from this survey, the Dental Guidance Notes recommend that a DWP of 65 mGy mm should be adopted as a local diagnostic reference level (DRL) for a standard adult panoramic radiograph [2]. Results from this study have been compared with this value.

Method

The dose measurement techniques used in this study were:

(a) ''In-beam'' detector and film: Measurement of peak dose within the X-ray beam at the receiving slit using a small solid state detector and determination of the beam width using X-ray film [3]. The DWP is calculated from the product of peak dose and beam width.

(b) Partial volume detector: Direct measurement of the summation of dose across the beam obtained from the partial volume irradiation of a pencil ionization chamber [4, 5].

(c) Thermoluminescent dosemeter (TLD) array: Measurement of dose at the receiving slit using a linear array of TLDs. This method can evaluate the DWP either from the incremental summation of dose across the beam or from the peak dose multiplied by the beam width [3, 6].

More details of the techniques used and the measurements made in evaluating them are given in the following paragraphs.

"In-beam" detector and film

A solid state detector that has an active width of 1.5 mm, which is marketed for measurement of the DWP, was used with an Unfors 511 Mult-O-Meter (Unfors Instruments AB, Billdal, Sweden). Measurement showed that the length of the sensitive region was approximately 4 mm. The detector was attached to the front side of the secondary collimator parallel to the slit and aligned visually with the slit. It is important that the detector is aligned accurately with the X-ray beam and is sufficiently narrow to enable it to lie entirely within the region of the dose peak in order to give an accurate result.

An assessment of the spatial response across the solid state detector was made using an X-ray beam from a radiographic unit collimated by a 0.2 mm wide lead slit. The detector was moved perpendicular to the slit in 0.2 mm steps by means of a micromanipulator with a vernier scale.

Images of the X-ray beam at the receiving slit of each orthopantomographic (OPT) X-ray unit were obtained by exposing Kodak T-mat L film. When this technique is employed, care is needed to avoid saturating the film. The width of the beam was obtained by measuring the film optical density with a microdensitometer (MKIII CS; Joyce-Loebl Ltd, Gateshead, UK) and determining the full width at half maximum (FWHM) (technique A1). However, a simple measurement using a ruler with a light box (technique A2) has been recommended [3] and this was also used in order to determine whether the errors involved were significant.

Partial volume detector

A pencil ionization chamber commonly used for CT dose index measurements (model No. 20X5-CT with a MDH 2025 electrometer; Radcal Corporation, Monrovia, NY) was attached in front of the secondary collimator, perpendicular to the slit. The DWP was taken as the product of the partial volume irradiation reading and the active length of the chamber (100 mm) (technique B).

TLD array

This technique involved measuring the dose profile at the receiving slit using an array of 34 TLDs mounted in a Perspex jig with 1 mm thick walls and lid. The TLDs used were high sensitivity LiF:Mg:Cu:P TLD-100H chips (0.38 mm thick and 3.2 mm diameter), calibrated in a 70 kVp X-ray beam against air kerma in air, measured using a 6 cm^3 chamber and a Radcal 9010 electrometer. The TLDs were placed on their edge, side by side in the jig, which was then positioned in the centre of the secondary collimator perpendicular to the slit. The TLDs were read out using a Harshaw 5500 TLD reader (Qados, Sandhurst, UK). The dose that each TLD received was obtained by correcting the readout for background radiation and applying a batch calibration factor. The spacing of the TLDs in the jig was determined from a measurement of the length of the arrays and found to be 0.40 mm. The DWP was calculated from the sum of the doses received by all the TLDs $d1$–$d34$, multiplied by the spacing w (technique C1) *i.e.*:

$$\mathrm{DWP} = w(d_1 + d_2 + ... + d_{34})$$

The doses recorded were plotted against position in the jig to give a profile of the dose distribution across the slit (Figure 1). The DWP was also calculated from the product of the maximum dose at the centre of the beam and the FWHM value (technique C2). Comparison of techniques C1 and C2 was used to confirm that the dose summation and the product of peak dose and FWHM gave similar results for the DWP.

Study method

Detectors and TLDs were all calibrated with respect to an ionization chamber with a Keithley Triad 35050A dosemeter system, which had a calibration traceable to a national standard. Relative responses were measured with the detector free in air and lying on a steel plate with a slit overlying a cassette to simulate actual exposure conditions. Based on these measurements, results obtained with the CT chamber and the TLDs were reduced by 5% to allow for the effect of backscatter. The Unfors detector is shielded from backscatter to a greater extent because of the metal its plate to its rear.

Measurements of DWP using the three techniques were made on 20 different OPT X-ray units from eight manufacturers (Table 1). The OPT units had been installed at various times over the previous 25 years and had an average age of 10 years. Successive measurements were made using each of the three techniques at the standard adult settings, typically; tube potential 70 kV, tube current 10 mA and exposure time 16 s, and values for the DWP derived for each technique. Experimental errors for the different techniques were estimated to be A1 $\pm$16%, A2 $\pm$19%, B $\pm$7% and C1 $\pm$8% and C2 $\pm$8%. Errors are expressed as percentages for each result, combining errors from individual components. The largest contributions were from the measurement of beam width using a ruler and the positioning of the Unfors detector.

The dose–area products (DAPs) for each unit were calculated from the product of the DWP and the beam length L [6]. The mean value for the DWP derived from measurement techniques A1, B and C2 was employed. The beam length L was measured with a ruler on a light box using the film exposed for technique A.

Results

The OPT units studied had a range of beam widths and examples of dose profiles obtained using TLDs for OPT units with average beam widths of 2.5 mm and 4 mm are shown in Figure 1. DWP results obtained using the different techniques are shown in Table 1. The two sets of values for the DWP obtained from the TLD data using different calculation methods, *i.e.* from dose summation and from the product of the peak and the FWHM, are compared in Figure 2. The ratio of the DWPs measured using the two techniques is 0.96 ± 0.02 (mean $\pm$ standard error of the mean (sem)), confirming that the

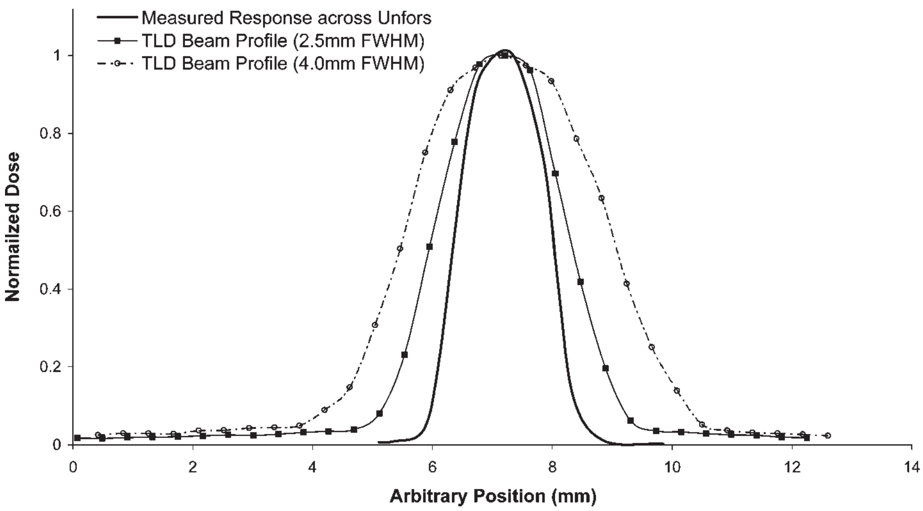

Figure 1. Dose profiles from orthopantomographic (OPT) unit with beam widths of 2.5 mm and 4 mm, measured using thermoluminescent dosemeters (TLDs), compared with the measured sensitivity profile across the width of the Unfors detector.

two methods give results which agree within experimental error. There is also reasonable agreement between the DWP results obtained using the TLDs, technique C1 and those from the pencil ionization chamber, technique B (0.91 ± 0.014, mean ratio $\pm$ sem) and the in-beam and detector method using the FWHM, technique A1 (0.85 ± 0.034, mean ratio $\pm$ sem), see Figure 3. The average DWP given by the different techniques are A1 61 mGy mm, A2 80 mGy mm, B 65 mGy mm, C1 72 mGy mm and C2 69 mGy mm. The standard deviation between the techniques A1, B and C2 averaged for the 20 units was 13%.

The Unfors detector should provide a reasonably accurate measurement of the peak dose, if it is positioned at the centre of the X-ray beam. The measured sensitivity response across the width of the Unfors detector is compared with two X-ray beam profiles in Figure 1. Misalignment of the detector and the centre of the beam by distances of 0.5 mm, 1 mm and 2 mm would give measurements lower by 2%, 16% and 59%, respectively, for a 4 mm beam width, and by 5%, 27% and 73%, respectively, for a 2.5 mm beam width. Results from technique A were more scattered than those from techniques B and C. Any misalignment between the detector and the beam would give a lower value for the peak dose and results for the DWP from technique A1 were slightly lower than for the other techniques.

The FWHM measured from films using the microdensitometer on five of the OPT units selected randomly, agreed to within 3% with the FWHM derived from TLD measurements. DWP measurements calculated using the data measured by the Unfors detector multiplied by the TLD profile FWHM, rather than the film FWHM, are included in Table 1 (technique A1). This was because a few of the films were saturated at the centre of the X-ray beam and so could not be used. The average beam

Table 1. Dose width product (DWP) measurements taken on different panoramic X-ray models at the standard adult setting

Code	Model/commissioned	kV	mA	Time (s)	Nominal Film/screen speed	Beam width (mm)	DWP (mGy mm):		
							Technique A1	Technique B	Technique C2
I	Sirona Orthophos (2002)	68	8	14	DR	3.5	43	38	45
II	Instrumentarium OPT (2002)	73	8	18	DR	2.5	32	51	48
III	Siemens Orthophos (1993)	69	15	14	Kodak T-mat L 400	3.0	40	53	48
IV	Morita Inc. Panex EC (1982)	70	7	14	Kodak T-mat L 400	4.5	58	43	41
V	Siemens Orthophos (1999)	74	14	13	Kodak T-mat L 250	4.1	44	52	65
VI	Instrumentarium OPT (1998)	66	10	18	Kodak Ekta 400	2.8	54	56	53
VII	Siemens Orthophos (1989)	66	15	15	Kodak T-mat L 400	2.3	45	57	61
VIII	Orion Cranex DC2 (1982)	69	6	19	Kodak T-mat L 400	5.5	65	54	49
IX	Planmeca PM2002CC (1990)	68	6	18	Kodak T-mat L 400	3.7	59	51	62
X	Siemens Orthophos (1990)	60	16	14	Kodak T-mat L 400	3.2	54	55	63
XI	Planmeca Proline (2002)	68	7	18	Kodak T-mat L 400	2.4	43	66	63
XII	Planmeca PM2002CC (1990)	68	6	18	Kodak T-mat L 400	3.7	62	52	63
XIII	Siemens Palomex (1987)	60	14	15	Kodak T-mat L 400	3.0	53	62	63
XIV	Planmeca Proline (2002)	68	7	18	Kodak T-mat L 400	3.0	55	61	66
XV	Morita Inc. Panex EC (1979)	70	8	16	Agfa Curix 250	4.5	60	66	75
XVI	Planmeca Proline (2002)	68	7	18	CR	3.8	58	64	79
XVII	Siemens Palomex (1976)	65	15	14	Kodak T-mat L 250	6.3	81	83	76
XVIII	Soredex Cranex (1993)	81	10	16	Agfa HTG Ortho 250	3.6	65	93	93
XIX	Yoshida Panoura (1990)	85	10	12	Ceahiplus 200	7.6	114	119	122
XX	Morita Inc. Panex EC (1980)	90	10	16	Kodak T-mat L 250	6.9	128	128	152

DR, digital radiography; CR, computed radiography.

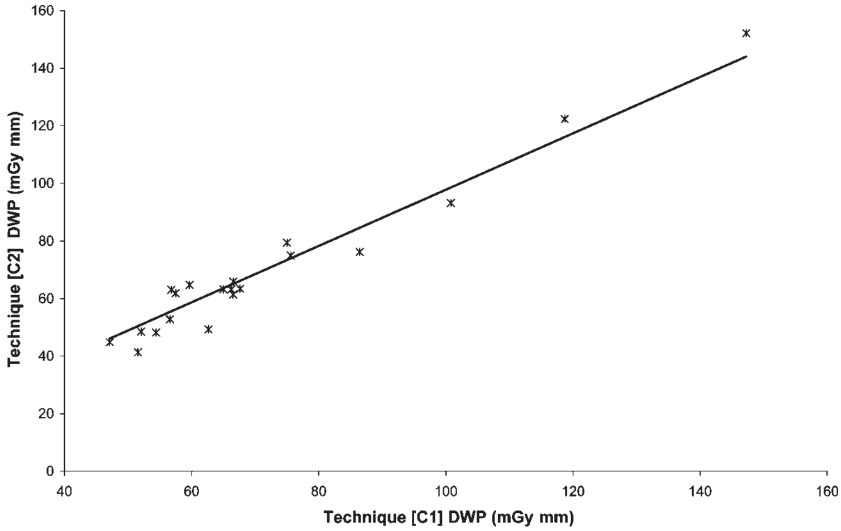

Figure 2. Plot of dose width products (DWPs) derived from thermoluminescent dosemeters (TLDs) showing the DWP derived from the product of the peak dose and full width half maximum (FWHM) against the DWP from the summation of the doses for all the TLDs across the beam. The line of identity is a 45° trendline.

FWHM of the OPT units included in this study is 4.0±0.3 mm. The average beam width measured from the film with a ruler and a light box was 20% higher than the FWHM, and the DWP results calculated using this (technique A2) were higher than those obtained using the other techniques (Table 1, Figure 3). The overestimation of the beam width was partially offset by the lower dose resulting from misalignment of the detector.

Values of DAP were calculated for each unit from the product of the average DWPs derived from techniques A1, B and C1 and measurements of the slit length *L* (Figure 4). The average beam length *L* was 136±2 mm and the average DAP was calculated to be 89±8 mGy cm^2. Values of the mean and third quartile DWP and DAP are compared with results from other studies in Table 2. The average DWPs were greater than the proposed DRL of 65 mGy mm [2] for 30% of the units. 400 speed index systems are recommended by the European Guidelines on Quality Criteria for diagnostic radiographic images [7]. The five units with the highest DWPs and DAPs all used films with speed indices of 200–250, while the two lowest both used direct digital radiography (DR), (Table 1, Figure 4).

Discussion

All three techniques gave results within reasonable agreement, but the errors associated with the in-beam detector and film technique A are larger than those for techniques B and C. For technique A, a microdensitometer was required for the measurements and it was important that exposures were limited to avoid saturation of the film emulsion in order that accurate results could be obtained. Measurement of the beam width with a ruler gave a result 20% greater than the FWHM and this method is therefore not appropriate. Use of a 35 mm film scanner (PrimeFilm 1800u; Pacific Image Electronics, Torrance, CA) linked to a PC with appropriate software (*e.g.* Scion Image; Meyer Instruments Inc., Houston, TX) and a calibrated film test strip to allow optical densities to be determined provides an inexpensive method for film scanning if a microdensitometer is not available, although this requires further limitation to be placed on the exposure because the measurable range in optical density is more limited. Another potential source of error in technique A is the visual positioning of the detector. The active area of the detector is 1.5 mm in diameter, which is similar to the width of the dose peak (Figure 1) with seven of the units studied having beam widths of

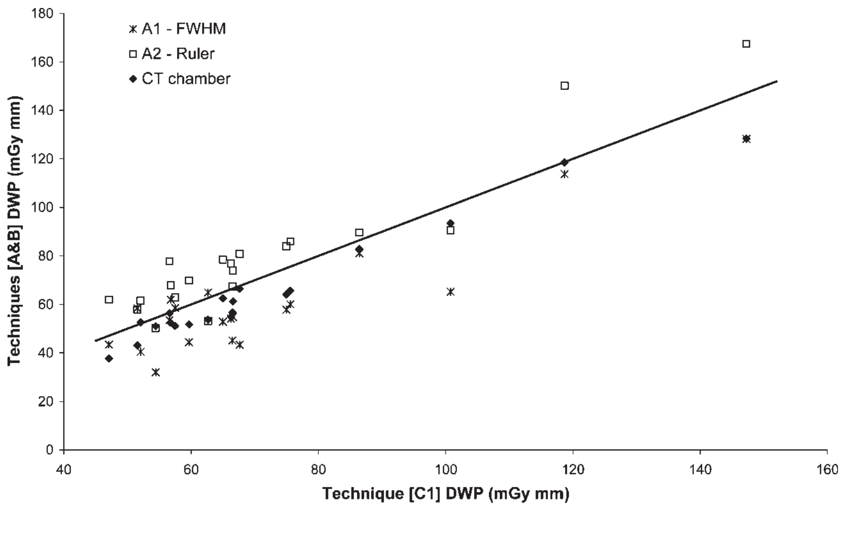

Figure 3. Plot of dose width product (DWP) measurements using an Unfors detector (techniques A1 – with full width half maximum (FWHM) derived from thermoluminescent dosemeter (TLD) profile and A2 – FWHM measured with a ruler and film) and a pencil ionization chamber (technique B), against the DWP derived from summation of doses across the beam from TLDs (technique C1). The line of identity is a 45° trendline.

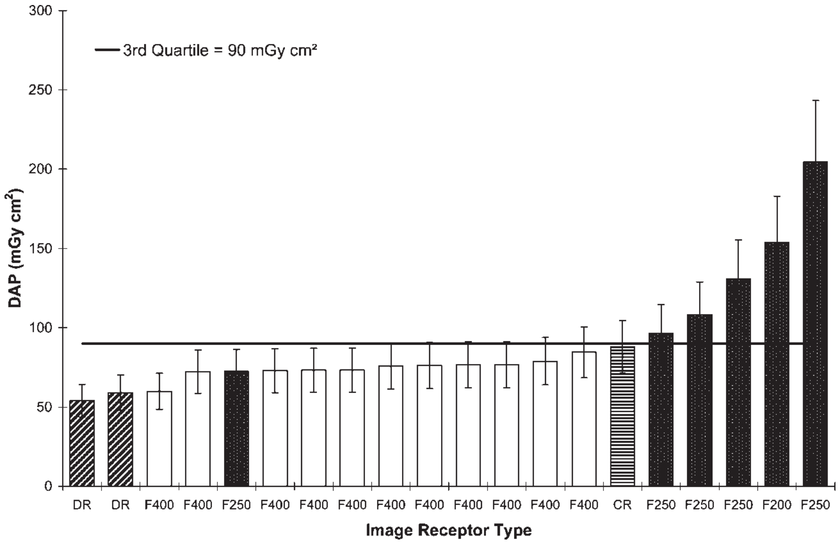

Figure 4. Bar chart showing dose–area product (DAP) values for a standard adult exposure for the 20 units studied. Data from film/screen combinations with indices of 200–250 (F250, dark) and 400 (F400, light), and from computed radiography (horizontal lines) and digital radiography (angled lines) systems are indicated by different shading.

3 mm or less (Table 1). The detector's active area must be positioned within 0.5 mm of the centre of the beam to keep errors to within $\pm 5\%$. A dedicated holder incorporating a phosphor screen to facilitate alignment of the detector with the X-ray beam is available from the supplier of the detector, although it was not used in this study.

The partial volume chamber method (B) is the most direct and simplest of the three techniques. Errors in the technique result from the calibration of the ionization chamber and the magnitude of the backscatter. When using this and technique A, care must be taken to ensure that the length of cable attached to the detector is sufficient to account for the rotational movement involved in the scan.

Method (C) using the TLD array is the most time consuming of the three techniques because of the handling and processing of the high sensitivity TLDs, which are brittle and need to be handled with care. The technique is accurate and so provides a useful method for dose comparisons, but is not recommended for routine use. It was useful for confirmation that values for the summation of the dose across the beam were similar to the product of the peak dose and FWHM. The agreement is closer than that reported in a previous study [6], probably because the earlier study used TLDs that were 0.85 mm thick. As a result, a limited number would lie within the X-ray peak, and this is likely to affect the accuracy of measurements of both the peak dose and the FWHM.

The average DWP from the three techniques assessed in this study is similar to the reference dose recommended by the NRPB [1] and to the mean values reported in other studies by medical physics departments [6, 8] (Table 2). In the present study, the third quartile was not significantly different from the proposed DRL [2] because there were a significant number of units with similar DAPs (Figure 4). The third quartile values in other studies tended to be higher than the DRL. This could reflect differences resulting from the sample size or distribution, measurement technique or poorer optimization. It will also be influenced by the 5% correction applied to account for backscatter in techniques B and C in the present study. DAP measurements were slightly less than results from other studies (Table 2) [5, 6, 9].

Six of the units tested in this study had a DWP greater than the DRL of 65 mGy mm. Five of these were using a film/screen combination with a nominal speed index of 200 or 250, so adoption of a 400 speed system, which could potentially reduce these doses by 40–50%, has been recommended with a proportionate reduction in exposure levels. Two of the units had DWPs that were close to the recommended suspension level of 150 mGy mm [10] and these units also had beam widths of 7–8 mm which were significantly broader than the maximum recommended value of 5 mm [2]. Investigation of the operation of the units has been recommended in order to optimize the system set ups and so reduce the exposures.

Table 2. Comparison of results of this study with published data

	Sample size	DWP (mGy mm):		DAP (mGy cm^2):	
		Mean	3rd Quartile	Mean	3rd Quartile
This study	20	65	67	89	90
Napier [1]	387	57	67		
Isoadri and Ropolo [4]	5	74	84		
Perisinakis and Damilakis [5]	6			113	
Williams and Montgomery [6]	16	65	76	113	139
Oduko [8]	26	69	80		
Tierris et al [9] (male)	62			101	117
(female)	62			85	97

DWP, dose width product.

Conclusion

This study has measured the DWP using three different techniques. The method using a semiconductor detector and film required the slit width to be assessed from the FWHM of the exposure peak, measured using a microdensitometer, as use of a simple ruler measurement [3] gave a result 20% greater than the true one. Uncertainty in alignment of the detector with the X-ray beam of more than 0.5 mm could result in a significant error. If this technique is employed, a microdensitometer and a dedicated alignment tool are recommended.

Use of a partial volume ionization chamber technique (B) provides a simple, robust method for direct measurement of the DWP, and is recommended as the technique of choice. The measurements are simple to record, avoid errors from positioning the radiation detector and do not require a measurement of beam width. The pencil type ionization chamber is also widely available and commonly used in diagnostic radiology departments for the measurement of CT dose index.

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