Table 1. Relative response of a cylindrical chamber as a function of electrode radius

	Relative response	
Electrode radius (cm)	Monte Carlo ± 95% conf. limits	Kristensen ± 95% conf. limits
Graphite		
0.0675	1.000	1.000
0.15	0.994 ± 0.006	0.997 ± 0.003
0.25	0.998 ± 0.007	0.996 ± 0.004
Aluminium		
0.0675	1.018 ± 0.007	1.008 ± 0.003
0.15	1.025 ± 0.007	1.021 ± 0.004
0.25	1.043 ± 0.008	1.035 ± 0.004

running more simulations but this was not considered worthwhile since the geometry of the experimental chambers was not exactly reproduced.

The figure shows good agreement between our results and Kristensen's. This serves the purpose of helping to verify both the measured results and the Monte Carlo calculation method. In particular it suggests that Monte Carlo modelling is a practical alternative to experimental measurement for the investigation of the effects of geometry and construction materials on the response of ionisation chambers.

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Assessment of the energy absorbed by patients during diagnostic radiology examinations by a calorimetric method

The Editor,
Sir,

The assessment of total radiative energy absorbed by patients in diagnostic radiology examinations has been considered in several recent papers (Gustafsson 1979, Harrison 1983, Shrimpton and Wall 1983, Shrimpton *et al* 1984). Whereas some authors suggest calculation by depth dose data, a more practical method is presented by Shrimpton and Wall (1983) and Shrimpton *et al* (1984). The latter authors calculate the energy fluence of X-ray beams from exposure measurements, and the fractional energy absorption by Monte Carlo calculations. The energy absorbed by the patient is obtained by multiplication of the energy in the X-ray beam and the fraction of this energy actually absorbed by the patient. Recently Nitzan *et al* (1983) suggested a simple and direct method for measurement of the energy fluence of X-rays. The X-rays are absorbed in a lead plate and the absorbed energy is evaluated by measurement of the temperature increase at the plate. The results were compared to those obtained by Epp and Weiss (1966) with a sodium iodide scintillator. The purpose of this note is to compare the results of all three methods (by exposure, by scintillation and by calorimetry) for energy fluence measurement.

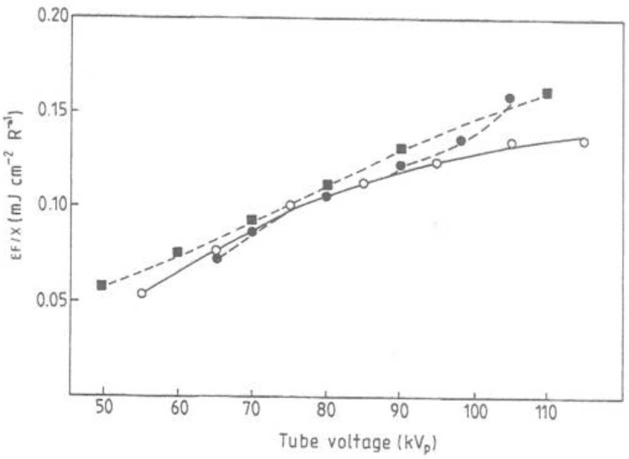

Figure 1. The energy fluence per Roentgen of X-ray beam as a function of tube voltage (1 R = 2.58 × 10^{-4} C kg^{-1}). ○, results obtained by total absorption calorimetry (Nitzan *et al* 1983); ●, data calculated from X-ray energy spectra (Epp and Weiss 1966); ■, data based on exposure measurements (Shrimpton *et al* 1984).

Figure 1 shows the energy fluence per Roentgen (EF/X) as a function of tube voltage ($1\ \mathrm{R} = 2.58 \times 10^{-4}\ \mathrm{C\ kg^{-1}}$), as measured by the three methods. Overall, there is good agreement between all these methods. Through the range 60–90 kV$_p$ the results agree within 10%. However, at lower (less than 60 kV$_p$) and higher (above 90 kV$_p$) tube voltages, the differences are somewhat larger. At low tube voltages the exposure method yields higher values and at high tube voltages the calorimetric method yields lower values than the other two methods. The lower values obtained by the calorimetric method can be explained by the increasing fraction of the scattered and transmitted radiation as the photon energy increases, wherefore a significant amount of the incident radiation is not absorbed in the lead plate.

The variation of EF/X apparent in all three methods shows that the ratio between energy absorbed by the patient and exposure is not constant, but depends on tube voltage. This reveals the inaccuracy of evaluating the total risk in diagnostic radiology examinations by exposure–area product *per se*, and emphasises the need for calculation of the energy absorbed by the patient as performed by Gustafsson (1979), Harrison (1983) and Shrimpton *et al* (1981). As a practical example, table 1 presents data on typical PA and lateral chest radiographs, taken at low and high voltages. Energy content is the product of the beam energy fluence (measured by the calorimetric method) and irradiated area. The total absorbed energy is derived from the energy

Table 1. Exposure–area product, energy content and absorbed energy for PA and lateral chest radiographs. Area, 1000 cm^2; SSD, 160 cm.

Position	kV$_p$	mA	Grid	Exposure–area product (R cm^2)†	Energy content (mJ)	Absorbed energy (mJ)
PA	65	12	–	18	1.37	0.95
PA	115	4	+	16	2.15	1.24
Lateral	75	25	–	46	4.55	3.21
Lateral	120	6	+	25	3.35	1.93

† Multiply these values by 8.7 to obtain the air kerma–area product (mGy cm^{-2}).

content by subtracting the transmitted beam (2% and 7% for low and high tube voltages respectively; Epp *et al* 1961) and the scattered beam (28% and 38% respectively; Stanton 1969, Hendee 1973). These values for the unabsorbed energy are consistent with those of Shrimpton *et al* (1984).

The different character of the two quantities, energy content and exposure–area product, is particularly evident at the PA position, where exposure–area product is reduced at high tube voltages, while energy content increases appreciably. (Note that even the absorbed energy increases at high tube voltages, despite the higher scattered energy.) These results confirm the claim that in order to evaluate the total risk in diagnostic radiology examinations, the total absorbed energy must be calculated.

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