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SPECTRAL DISTRIBUTIONS FROM ^{60}Co THERAPY UNITS

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The photon beam from a ^{60}Co therapy unit consists of not only the initial 1.17 and 1.33 MeV photons but also photons whose energies have been reduced by scattering processes in the source, its spacer sleeve, the housing and the collimator. The energy distribution of the scattered photons is affected by the consctruction of the source and its surroundings. Thus differences in the spectral composition of the beam from different therapy units can be expected.

ICRU (1970) presented calculated photon distributions for different sources and collimators. Experimental investigations of the energy distribution of the photons in the beam from ^{60}Co sources have been made by COSTRELL (1962) and AITKEN & HENRY (1964). The spectrum from a cobalt therapy unit has been investigated by SCRIMGER & CORMACK (1963) and GOODWIN & OPAL (1965). Differences between measured photon field parameters have been reported and it has been suggested that one explanation might be the possible differences in the spectral distribution of different sources (Review of Suppl. No. 10, Brit. J. Radiol. 1968, TSIEN 1969, ALMOND 1969).

As ^{60}Co gamma radiation is used as a reference radiation quality for dosimetry of photon and electron radiation from accelerators (Recommendations by the Nordic Association of Clinical Physics 1972) and since the response of most

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Table 1

The clinics visited and the types of therapy units. Units A, B and F are equipped with long multiplane collimators of the type described by JOHNS & MCKAY *(1954). The remaining three units have relatively short collimators.*

^{60}Co unit		Radiation Therapy Department at	Diameter of source (cm)	Field sizes (cm × cm)	SSD (cm)	Notes
A	Picker C-3000	Centrallasarettet, Eskilstuna	1.5	4×4—18×18	80	With trimmers
B	Picker C-3000	Regionssjukhuset, Linköping	2.0	6×6—18×18	80	
C	AECL Eldorado Super G	Radiumhemmet, Stockholm	2.0	4×4—18×18	100	
D	Siemens Gamma-tron 1	Umeå lasarett, Umeå	2.0	4×4—18×18	100	
E	Siemens Gamma-tron 3	Akademiska Sjukhuset, Uppsala	2.0	6×6—18×18	100	With trimmers
F	Barazetti Hyperion	Regionssjukhuset, Örebro	2.0	6×6—18×18	100	

dosimeter systems depends on the spectral distribution of the photon radiation, it is of importance to know the possible variations in the photon spectrum for different cobalt units as well as how much the possible variations in such spectra can be expected to affect the exposure measurements and thereby the reliability of such radiation as a reference. This report presents the results of a comparison of measurements of the spectral distribution of the photons in the centre of square fields of six different ^{60}Co units (Table 1) in April 1971, and calculations of the differences to be expected in terms of dosimeter calibration.

Methods. The measurement of a photon spectrum using a sensitive detector placed directly in the beam of a therapy unit implies great difficulties due to the high photon fluence rate. Thus an indirect measuring procedure is more practical. In the measurements presented here, a method based on a principle devised by SCRIMGER & CORMACK (1963) has been applied (Fig. 1). A 1 mm thick aluminium foil is used as a scatterer and placed in the centre of the primary beam. The photon radiation scattered within a small solid angle is detected by a well collimated and shielded 7.6 × 7.6 cm NaI(Tl)-scintillation detector in combination with a multi-channel pulse height analyzer.

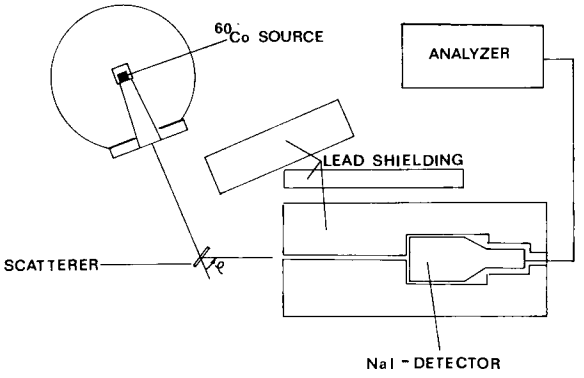

Fig. 1. The experimental arrangement for spectral measurements with a ^{60}Co source. 7.6 cm $\times$ 7.6 cm NaI-detector.

The pulse height distribution obtained is then converted to the spectrum of the photons in the primary beam. The conversion is made in three steps. First the pulse height distribution is corrected for possible drift in the spectrometer using an energy calibration with a ^{137}Cs gamma source. The second step is the conversion to the spectrum of those photons which have been scattered by the aluminium foil and recorded by the detector using a square correction matrix, M, with the property $P = F \times M$, where P is the pulse height distribution obtained when a photon distribution F hits the crystal. Thus this matrix expresses the photon energy response of the spectrometer and is based upon corrected and normalized pulse height spectra for monoenergetic photons with energies up to 800 keV in steps of 20 keV. These spectra have been obtained by interpolation between twelve approximately monoenergetic photon sources of different energies (LÖFROTH 1971). The photon distribution in the beam which hits the crystal is obtained by successive approximations with the aid of the matrix (HETTINGER & STARFELT 1958, SCOFIELD 1960, SKARSGARD et coll. 1961). The calculation work is terminated when a pulse height distribution calculated from the most recent approximation to the photon distribution is according to predetermined criteria, close enough to the measured pulse height distribution. This method has been tested on pulse height distributions generated by the matrix from applied photon distributions. The photon distributions obtained from the matrix agreed with the applied distributions with the exception of a smoothing caused by the interval width of the matrix.

In the third step, knowing the scatter angle, the photon energy distribution in the primary beam of the therapy unit is then calculated using compton scattering cross-sections and energy degradations. The accuracy of these conversions has been tested by calculating the primary photon distribution from pulse height

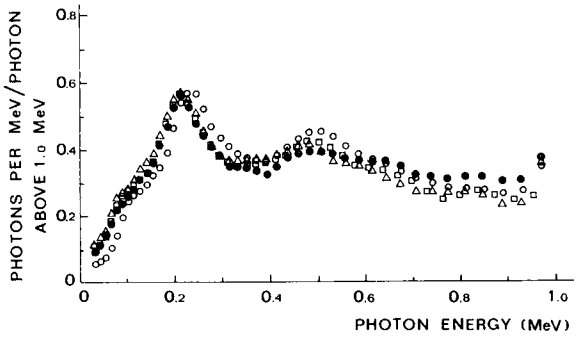

Fig. 2. Normalized photon distributions below 1.0 MeV from the new unit D measured on three different occasions (□ ○ △ respectively), field size 10 cm × 10 cm. The fourth curve (●) was measured with the same unit and field size but with the old source.

distributions measured at different scatter angles, φ, in the same photon beam. Here the resolution decreases with increased scatter angle but the photon spectra nevertheless showed satisfactory agreement with one another.

An indication of the precision of the method has been obtained by making measurements on the same unit (Unit D) with identical SSD and field size at three different occasions. The calculated photon distributions are presented in Fig. 2 including an additional spectrum from an earlier source in the same unit.

Due to the limited resolution of the scintillation spectrometer, energy-degraded photons in the primary beam with energies larger than 1 MeV cannot be differentiated from the primary photons. Therefore, in our calculations, all photons with an energy larger than 1.0 MeV have been treated as primary photons with an average energy of 1.25 MeV.

Results

Fig. 3 gives normalized spectra below 1.0 MeV from four of the therapy units with field size 10 cm × 10 cm. The backscattered radiation from the source and its nearest surroundings produces a peak at 0.2 to 0.3 MeV with an amplitude which varies slightly from source to source. Unit A, which has a smaller source than the other units, produced a spectrum with a smaller backscatter peak. The greatest difference between the curves is seen in the energy interval 0.4 to 0.8 MeV corresponding to single scattering 80° to 40°. Here unit C has clearly a greater fraction of scattered photons than the other units. The B and D curves, which are not shown in Fig. 3, lie in the midst of the curves presented in the figure.

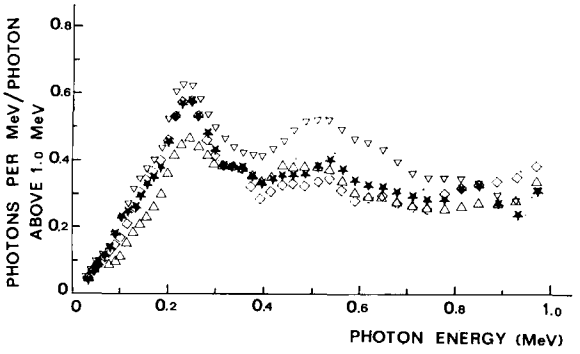

Fig. 3. Normalized photon distributions for four different units (A△, C▽, E★, F◇), field size 10 cm × 10 cm.

The dependence on field size is demonstrated in Fig. 4 using the photon spectra from units C and F with field sizes of 6 cm × 6 cm and 15 cm × 15 cm. For unit C, which has a short collimator, the field size has a greater influence on the photon spectrum at energies above 0.3 MeV than for unit F, which has a multi-plane collimator. The field size influence on unit F is most evident at energies above 0.7 MeV. The primary cause for the increase in the fraction of scattered radiation with increased field size is the greater contribution from the surroundings nearest the source.

A comparison with the work of AITKEN & HENRY (1964) on sources with a diameter of 3 cm shows the backscatter peak in our spectra to be considerably lower, while their spectra also contained a greater fraction of photons in the energy interval 0.4 to 0.6 MeV, photons which have been scattered in the surroundings closest to the source. This latter peak, caused primarly by the

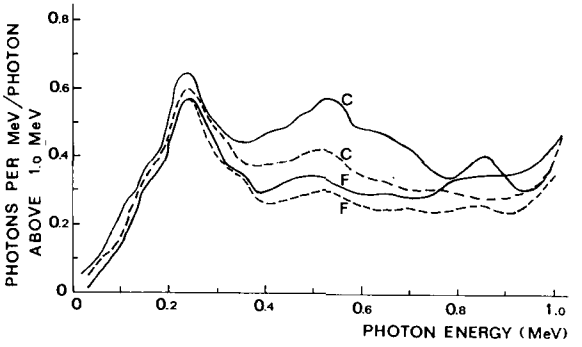

Fig. 4. Normalized photon distributions for two units with field sizes 6 cm × 6 cm (- - -) and 15 cm × 15 cm (—).

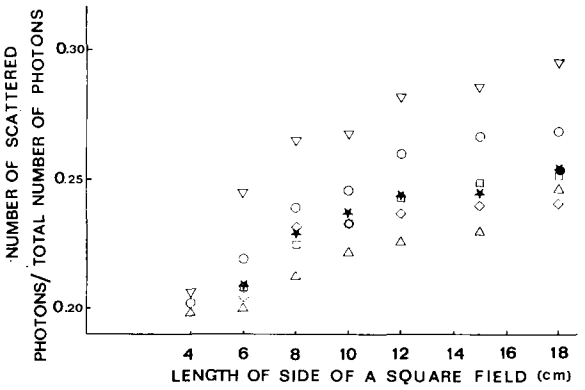

Fig. 5. The ratios of the number of photons below 1.0 MeV to the total number of photons for each of the units and all field sizes. SSD: A △ 80 cm, B □ 80 cm, C ▽ 100 cm, D ○ 100 cm, E ★ 100 cm, F ◇ 100 cm.

source capsule and the shielding head, has also been described by COSTRELL (1962). A simple measure of the quality of the photon radiation is the ratio of the number of photons below 1.0 MeV to the total number of photons. These ratios for all units and field sizes are given in Fig. 5.

Exposure calculations on our photon spectra revealed that the exposure from scattered photons with energies below 1.0 MeV amounts to between 10 and 17 per cent of the total exposure. Fig. 6 gives the exposure in the beam as a fraction of the exposure that would have been obtained had all of the photons in the beam had an energy of 1.25 MeV. This fraction was 85 to 90 per cent, which is in agreement with corresponding values given in ICRU (1970). A small overestimation of the exposure has been made by using 1.25 MeV as the average energy for all photons with energies above 1.0 MeV.

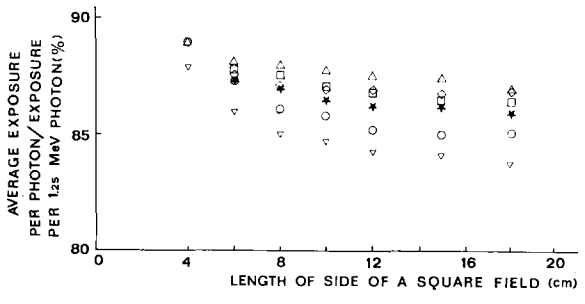

Fig. 6. The exposure expressed as the fraction of the exposure which would have been obtained had all the photons had an energy of 1.25 MeV. (SSD and symbols as in Fig. 5.)

Table 2

Averages of measured tissue-air ratios at 2 cm depth in water with the six sources and the corresponding values from GUPTA & CUNNINGHAM *(1966)*.

Tissue-air ratios, ^{60}Co at depth 2 cm							
Length (cm) of side of a square field at depth 2 cm	6	8	10	12	15	18	20
GUPTA & CUNNINGHAM	0.976	0.992	1.004	—	1.025	—	1.040
Our measurements	0.989	0.997	1.007	1.015	1.026	1.035	—

Discussion

Given the energy response of present dosimeter systems, the differences in the spectral distributions presented here are so small that they can be expected to result in a variation of the calibration constant of less than 0.1 per cent for a given instrument exposure calibrated with different cobalt units. Thus, for clinical dosimetry, the photon radiation from a ^{60}Co therapy unit is a satisfactory reference radiation quality.

In order to estimate the effects the differences in the measured photon spectra would have on exposure determinations at depths of 2 cm and 5 cm in water based on measurement of the exposure at the corresponding point in air, attenuation calculations were performed on the exposure distributions. A ratio was then made of the calculated exposure in free air to the corresponding value after narrow beam attenuation in water at depths of 2 cm and 5 cm, respectively. These ratios had a range of less than 0.3 per cent of the average with a field size of 10 cm $\times$ 10 cm. This is the estimated magnitude the influence variation in radiation quality from different ^{60}Co units may have on the determination of absorbed dose at 5 cm depth or less in water based on an exposure measurement in free air and using tissue-air ratios.

An experimental investigation of the influence of the different spectral distributions on the tissue-air ratio was made. Tissue-air ratios were determined with an ionization chamber at 2 cm depth in a water phantom for the different therapy units and field sizes. No relation between experimentally determined tissue-air ratios and the magnitude of the scattered fraction of radiation could be demonstrated. These measured tissue-air ratios agree to within 0.3 per cent with published values (GUPTA & CUNNINGHAM 1966) for field sizes greater than 10 cm $\times$ 10 cm (Table 2).

Acknowledgements

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SUMMARY

The energy distribution of photons in beams of six different ^{60}Co therapy units has been investigated using a NaI(Tl)-scintillation spectrometer. Differences in photon energy distribution were demonstrated. Calculations on the different photon distributions show that the differences expressed in terms of measured exposure are so small that the photon radiation from a ^{60}Co therapy unit can be considered a good reference radiation for dosimetry with accelerator-produced electron and photon radiation for medical use.

ZUSAMMENFASSUNG

Die Energieverteilung von Photonen im Strahlengang von sechs verschiedenen ^{60}Co Therapieapparaten wurde unter Anwendung eines NaI(Tl)-Szintillations-Spektrometers untersucht. Es wurden Unterschiede für die Verteilung der Photonenenergie nachgewiesen. Berechnungen über die verschiedenen Photonenverteilungen zeigen, dass die Unterschiede, ausgedrückt als gemessene Exposition, so gering sind, dass die Photonenstrahlung von einem ^{60}Co Therapieapparat als eine gute Referenzstrahlung für die Dosimetrie mit Accelerator-hergestellten Elektronen und Photonenstrahlung für medizinische Zwecke angesehen werden kann.

RÉSUMÉ

Les auteurs ont étudié la distribution d'énergie des photons dans les faisceaux de 6 unités différentes de traitement par le ^{60}Co au moyen d'un spectromètre à scintillation au NaI(Tl). Ils ont mis en évidence des différences dans la distribution de l'énergie des photons. Les calculs sur les différentes distributions de photons montrent que les différences exprimées en termes de dose mesurée sont si petites que la radiation photonique d'une unité de traitement par le cobalt peut être considérée comme une bonne radiation de référence pour la dosimétrie appliquée à l'usage médical de l'irradiation par les électrons produits par un accélérateur et par les photons.

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