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MEASUREMENTS OF PRIMARY SPECTRA FROM A KILOCURIE ^{60}Co UNIT AND A 6 MeV LINEAR ACCELERATOR

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Spectral measurements have been made of gamma radiation from a T.E.M. Stabilatron kilocurie cobalt 60 unit and of roentgen radiation from a Varian Clinac 6 MeV linear accelerator with a NaI crystal spectrometer, both units normally used by us for radiation therapy. The high photon flux density from these two types of radiation sources, especially the pulsating radiation from the accelerator, necessitates a reduction in the intensity. This is performed by spreading in Al foil (SCRIMGER & CORMACK 1963, BENTLEY et coll. 1967, LÖFROTH 1970), which reduces both intensity and energy, and by collimation. Multiple counts are reduced by means of a dual delay line amplifier (CHASE & SVELTO 1961).

A response matrix (SAM et coll. 1968) for the detector was constructed from the monoenergetic gamma ray source spectra and applied to obtain the gamma ray and roentgen spectra from the measured pulse height distribution. An iterative unfolding procedure (SKARSGÅRD et coll. 1961) solved the matrix equation:

$$P = R \times N$$

where P is the measured pulse height distribution, R the response matrix of the detector and N the scattered spectrum. The primary photon spectrum is calcu-

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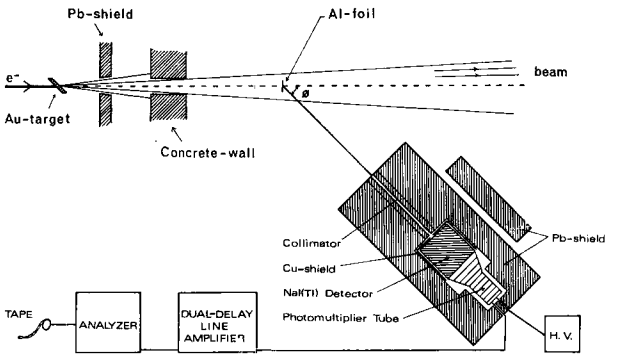

Fig. 1. Experimental arrangement for measurements on the linear accelerator.

lated from the once scattered spectrum by means of the Compton energy-angle relation and the Klein-Nishina formula.

Experimental method and apparatus. The experimental arrangement appears in Fig. 1. The spectrometer consists of a Harshaw matched window line assembly with a NaI (Tl) crystal (diameter 12.7 cm) and a EMI 9530 photomultiplier encapsulated in a lead shield of 10 cm minimum thickness. A filter of 3 mm Cu between the crystal and the lead shield reduces the lead fluorescence. The lead in front of the crystal is 30 cm thick and blocks of lead lie between the radiation source and the spectrometer. The collimator, which is detachable, is cylindric, 30 cm in length with a diameter of 3 or 5 mm. The spectrometer is placed on a movable truck with facilities for lining up. Measurement of the primary accelerator spectrum is performed with the spectrometer placed behind a concrete wall (density: 3.5 g/cm^3) of 160 cm thickness with a hole, 6 cm in diameter, for free passage of the beam. It is thus possible to reduce the high level background that exists in the accelerator room at the pulse moment from the target head and the wave guide.

Pulse height distributions were measured by passing the output from the photomultiplier directly through a double-delay line clipped linear amplifier into a multichannel pulse height analyser. The amplifier was modified by NIELSEN for this purpose after CHASE (1961) and has a clipping time of 0.35 μs. If the signal is single in the clipping time, no pile-up will appear. The gain and the angle was chosen so that a fifth of the channels fell out of the energy range; the pile-up was checked qualitatively in this way but no correction proved necessary. The gain of the whole system was checked before each run against a ^{57}Co and a ^{137}Cs point source. Thin aluminium foils with an area of 16 cm^2 placed 80 cm from the crystal surface scattered the radiation without significant multiple

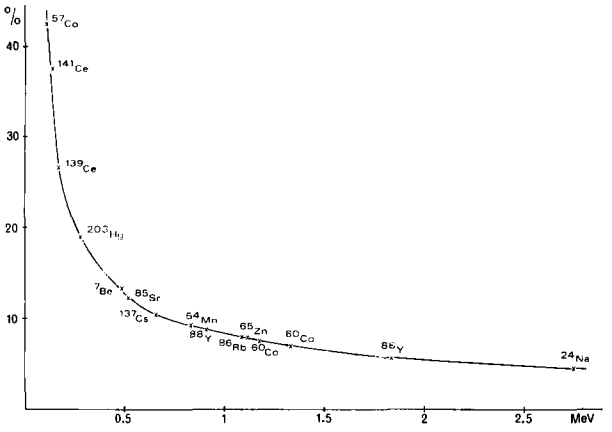

Fig. 2. Measured resolution as a percentage of the photon energy for the spectrometer. Collimator diameter: 5 mm.

spreading. For checking the experimental principle, foil of a thickness ranging from 0.17 to 2.0 mm and spreading angles from 10° to 60° were tried on the cobalt unit.

Calibration and analysis of the pulse height distribution. The response of the detector may for a given energy range be represented by a quadratic matrix, including the possible effects of the shield. The pulse height spectra used to form the response matrix were detected from monoenergetic gamma ray sources prepared from commercially available solutions. Point sources were made from the solutions with ion exchange resins, except for the ^{24}Na solution, where Na^+ ions were precipitated with $K(Sb(OH)_6)$ and dried. The resin for the cations was Dowex 50 W × 8 with a diameter less than 1 mm of the corns. Activities of 10 to 200 μCi were attainable with these preparation methods.

The point sources were placed at a fixed geometry near the front of the collimator and in the position of the spreading foil. A series of spectra from the applied isotopes were measured and used for interpolation to form the response matrix for different collimators and various energy ranges (gain). The resolution measured for the spectrometer appears in Fig. 2.

A 49 × 49 and a 99 × 99 matrix were constructed from the measured resolution and photo fraction (peak/total ratios) (Sam et coll. 1968). The small deviation of the photopeak from the gaussian shape on the low energy side was taken into account; after the subtraction of the gaussian distribution from the photopeak the residue was treated as the Compton part and used for interpolation to the matrix. The columns in the matrix are normalised to the total efficiency of the crystal for the respective energy and matrices with both linear

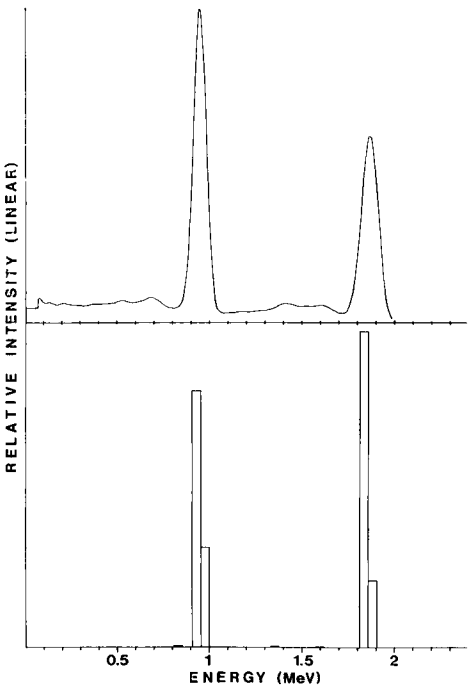

Fig. 3. Measured pulse height distribution for the ^{88}Y point source ($\sim$ 150 μCi) and the iterated photon spectrum after 286 iterations with a 49 × 49 response matrix.

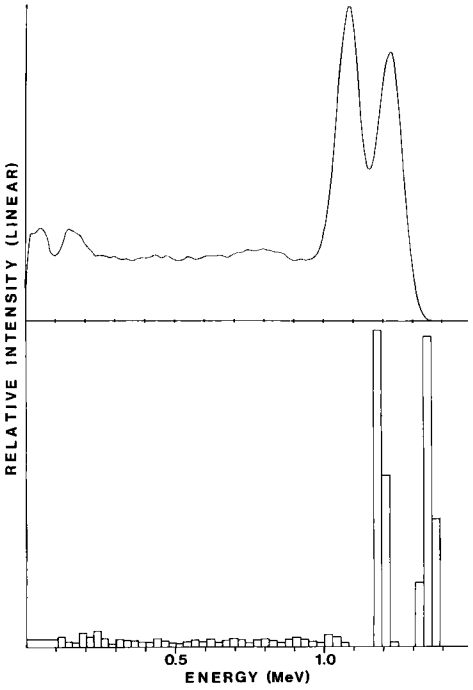

Fig. 4. Measured pulse height distribution for the Stabilatron ^{60}Co source after 15° spreading in a 0.5 mm Al foil and the iterated primary photon spectrum after 27 iterations with a 99 × 99 response matrix.

spacing and bin width proportional to the square root of the energy are employed. By placing point sources of known strength in various distances along the collimator axis, the collimator penetration was checked and good agreement with Simons formula for cylindric holes reached. Correction was made for the different penetrations at varying energy (Simons 1961).

An iterative method was used for unfolding the pulse height distribution (Skarsgård et coll. 1961). Fig. 3 indicates unfolding of an ^{88}Y calibrating spectrum with a 49 × 49 linear matrix. The iteration stopped when the convergence ceased or when the criterion by Skarsgård et coll. was reached.

The computer programmes are written in fortran extended for the CDC—6 400 machine at the University of Århus. These analyse the calibration spectra, perform the various corrections and the iterative procedure, and calculate and plot the original primary photon spectrum.

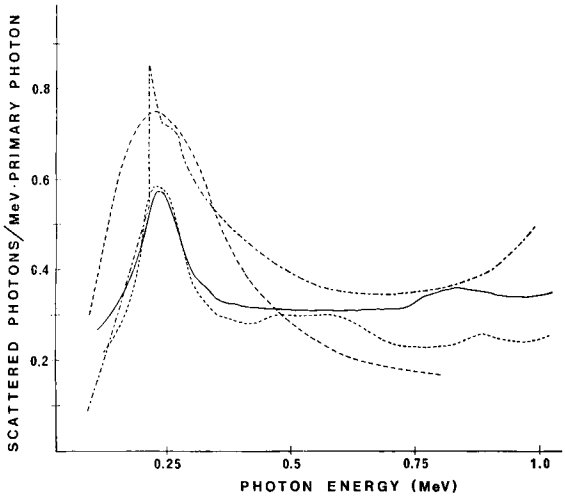

Fig. 5. Scattered part of the primary radiation from different ^{60}Co sources. – – – – CORMACK & JOHNS (1958), calculated, — — — SCRIMGER & CORMACK (1963), ------ LÖFROTH (1970), ——— Present data.

Results and Discussion

Stabilatron. A typical set of results from a measurement on the Stabilatron ^{60}Co source appears in Fig. 4. Good resolution of the two peaks appears at a spreading angle of 15° in the pulse height distribution; the resolution decreases at increasing angles and at 60° no separation of the peaks is apparent. The uncertainty of the angle is ± 0.5°. By varying the foil thickness between 0.5 and 2.0 mm Al a linear influence on the intensity is obtained with no influence on the resolution; this confirms that no important multiple spreading in the foil exists. The measurement has been carried out with SSD (source to skin distance) of 80 cm for the foil position on the central axis at which distance the field size is 5 cm × 5 cm. The diameter of the collimator in front of the detector is 5 mm. The iterated primary photon spectrum (Fig. 4) indicates appreciable seperation of the two peaks for angles up to 45°; the ratio between the relative photon content in the two peaks is $I_{1.17}/I_{1.33} = 0.98$ in Fig. 4.

The scattered radiation in the iterated spectrum coming from scattering within the source itself in the surrounding capsule and from the shield and collimating device is illustrated in Fig. 5. It is an average spectrum from five measurements with a spreading angle of 15°, SSD = 80 cm and field size 5 cm × 5 cm. Comparison with the calculations of CORMACK & JOHNS (1958) and two other measurements (SCRIMGER & CORMACK 1960, LÖFROTH 1970) shows excellent agreement with the measurement carried out by LÖFROTH with the Siemens Gammatron I with SSD of 1 m and a field size of 5 cm × 5 cm, especially for the

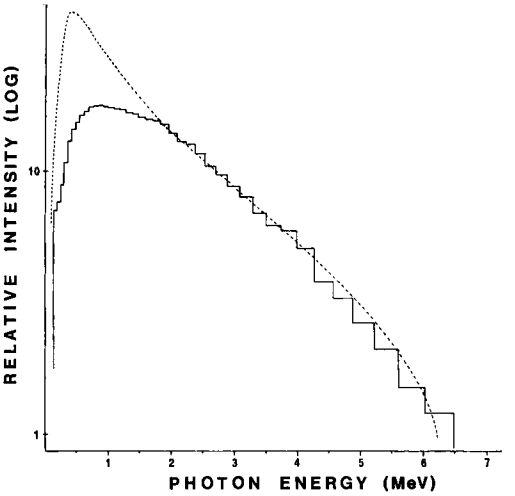

Fig. 6. Experimental bremsstrahlung energy spectrum for the Varian 6 MeV linear accelerator compared with the theoretical thin target curve corrected for filtration in target, window and field flattener filter. - - - - - - Calculated (SCHIFF, 0°), ——— Present data.

low energy photons. A difference in the collimating device will produce a deviation in the high energy part of the scattered spectrum according to the work of CORMACK & JOHNS (1958); they calculated that the scattered radiation yields 28.7 per cent of the primary radiation. Integrating their curve up to 1 MeV yields 16.7 per cent; the exposure from the scattered radiation up to 1 MeV formed 13 ± 2 per cent of the primary radiation in the present investigation.

Accelerator. The measurements on the linear accelerator are considerably more difficult due to the pulsating radiation with the enormous photon flux density of 10^8 per cm^2 per pulse at 1 m from the target. The duration of the pulses are 1.5 μs with a frequency of about 100 Hz. On account of the circle time ($\sim$ 100 μs) of the analyser system, it is only possible to obtain at the most one photon for every pulse, which means a relatively long recording time for reasonable statistics. A spectrum measured at 34° ± 0.5° spreading with 1.5 mm Al foil and a 5 mm collimator, FSD = 685 cm, appears in Fig. 6. The dose rate of the accelerator is 200 rad/min, or normal for radiation therapy.

The measurement is compared with a theoretic calculation for a thin target by the SCHIFF formula (1951) integrating all angles of the electrons scattered in the target and with zero degrees for the angle between the incoming electron and the emitted photon (transmission target). A total energy of 7 MeV for the electrons is used in the calculation. The curve is corrected for filtration in the gold target ($1/2\ t_0 = 0.75$ mm), in the nickel window (0.2 mm) and in the field flattener filter of stainless steel (14.2 mm).

Good agreement is secured between the measurement and the thin target curve

for photon energies above 2 MeV. Most of the photons radiated from the target in a forward direction come from electrons, which are scattered by small angles; only a small amount of multiple spreading is thus possible (HISDAL 1957).

Since high-energy bremsstrahlung quanta are more likely to be emitted with small angles than low energy ones the spectrum distribution will follow the thin target curve for the high-energy part but deviate for the low-energy part, where the thick target effects are considerable. The calculation of the filtration in the target is also somewhat arbitrary and will exert much influence on the low-energy spectrum.

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SUMMARY

Measurements have been made of a kilocurie Cobalt 60 unit and a 6 MeV linear accelerator with a NaI crystal spectrometer. Spreading of the primary radiation by Al foil and an iterative procedure for unfolding the pulse height distribution were applied. The dose of the scattered part of the primary ^{60}Co radiation reaches 13 $\pm$ 2 per cent of the total. The accelerator spectrum is compared with a theoretical thin target curve for bremsstrahlung in a forward direction.

ZUSAMMENFASSUNG

Es wurden Messungen einer Kilokurie Cobolt-60 Einheit und eines 6 MeV Linearacceleratorators mit einem NaI Kristall Spektrometer vorgenommen. Es wurden die Streuung der Primärstrahlung durch eine Aluminiumfolie und ein Wiederholungsverfahren zur Entfaltung der Pulshöhenverteilung verwendet. Die Dosis des gestreuten Teils der primären ^{60}Co-Strahlung erreichte 13 $\pm$ 2 % der Gesamtdosis. Das Acceleratorspektrum wird mit einer theoretischen Dünn-Target-Kurve für die Bremsstrahlung in Richtung nach vorne verglichen.

RÉSUMÉ

L'auteur a fait avec un spectromètre à cristal de NaI des mesures sur le rayonnement d'un appareil chargé d'un kilocurie de cobalt 60 et d'un accélérateur linéaire de 6 MeV. Il a utilisé la dispersion du rayonnement primaire par une feuille d'Al et une procédure itérative pour exposer la distribution supérieure pulsée. La dose de la partie diffusée du rayonnement primaire du ^{60}Co atteint 13 $\pm$ 2 pour-cent au total. Le spectre de l'accélérateur est comparé avec une courbe théorique sur cible mince pour le rayonnement de freinage en direction antérograde.

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