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A. Benvenuti, P. Blasi, P. R. Maurenzig and P. Sona: ON THE BACKSCATTERING OF ELECTRONS ON SILICON DETECTORS.

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1) INTRODUCTION -

Silicon detectors have been widely used in nuclear spectroscopy but, so far, their application as beta-particle detectors has been rather limited and only a few results have been obtained[1, 2, 3].

The main difficulty encountered is due to the backscattering of electrons on the detector. This effect seriously distorts the observed beta spectra and affects the measurements of the intensity ratio of internal conversion lines, as has been reported by many authors[1, 2, 3].

There is no theory to possibly help in the correction of experimental data for such a complex effect which drastically depends on the specific experimental conditions. It is therefore impossible to make use of the data of other laboratories and the backscattering effect must be investigated in every single case, with the same experimental set up actually used in the measurements.

Therefore a study of the magnitude of this effect seemed to us worthwhile in order to test the possibility of a reliable correction method.

(x) - Work done in the frame of the EURATOM-CNEN contract for fundamental research in nuclear physics.

2) EXPERIMENTAL PROCEDURE -

The conventional method[4, 5] of measuring the response function of the detectors to monoenergetic electrons has been adopted to determine the magnitude of the backscattering effect.

Monoenergetic electrons were obtained by selecting the K-internal conversion electrons of some nuclear transition through a coincidence with the x-ray following their emission. The radioactive sources were obtained by depositing a drop of the active solutions on a thin film of VYNS previously treated with insuline. The resulting sources were about 5 mm. in diameter.

The x-ray detector was a NaI (Tl) scintillator 1 mm. thick x 5 cm diameter (type 44SB1 - Quartz and Silice) with a 0.2 mm berillium window.

Two semiconductor detectors were used in the course of the measurements; one of them (ORTEC TYPE SBFJ 2000) was of the surface barrier type with 2 mm sensitive depth (at 270 volt bias) and 200 mm^2 area; the other one was a TMC 1 mm x 200 mm^2 lithium-ion-drift detector.

Signals from the detector were amplified by a low noise charge sensitive preamplifier and a standard amplifier; pulses were then fed to a 512 - channel pulse height analyser. The coincidence system was a conventional fast-slow with timing provided by the zero cross of two double-delay-line shaped pulses (see block diagram in fig. 1).

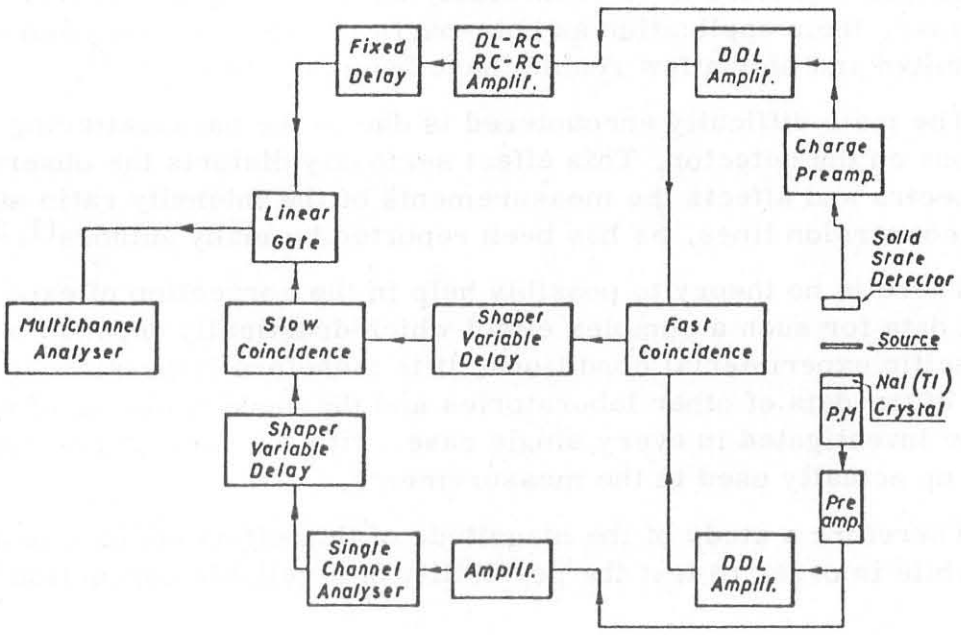

FIG. 1 - Block diagram of the fast-slow coincidence system.

The choice of the resolving time T is dictated by two conflicting requirements. In fact a high true-to-random coincidence ratio requires a small T. A low value of T, however, introduces a loss in the true coincidence rate, because the noise produces a spread in the zero crossing time; this effect is especially felt at low energies. As a sort of good compromise we chose 2T = 150 nanoseconds which allows undirstorted detection of the backscattering down to ~ 70 Kev. When the energy of the selected electrons is low (e.g. In^{114}, Cd^{109}) it is important to record the response function down to still lower energy (see next section) and in these cases we used a simple slow coincidence circuit with 2T = 3 microseconds.

In the experimental set up the semiconductor detector and the scintillation counter were mounted inside a vacuum chamber and aligned on a vertical axis along which the source could be continously shifted. The vacuum chamber used (described in detail elsewhere[6]) had provisions for detector cooling both with liquid nitrogen and dry ice-alcohol mixture and for presenting to the detector in turn up to four sources (in various positions) without breaking the vacuum.

3) EXPERIMENTAL RESULTS AND CORRECTION METHOD -

Fig. 2, 3, 4, show some typical response functions of the TMC lithium drifted silicon detector for different energies of impinging monoenergetic electrons.

The three response functions were measured in the same geometry. The silicon detector was cooled down to liquid nitrogen temperature and a 70 volt reverse bias was applied.

In order to investigate the influence of several experimental parameters we define a backscattering coefficient p as the ratio between the number N_B of electrons which lose only a fraction of their energy in the detector and the number N_I of impinging monoenergetic electrons:

$$p = \frac{N_B}{N_I} \cdot$$

N_B is evaluated as follows. The average value $\bar{R}$ of the response function R(E) is evaluated over an energy interval which extends from 70 KeV (30 KeV for slow coincidence measurements) up to a properly choosen energy (usually 3 f.w.h.m. from the full energy peak). N_B is then assumed to be

$N_B = \bar{R}E$ (E being the energy of the peak).

We have first studied the dependence of p on the counting geometry. The variation of p with the source to beta detector distance d is shown in fig. 5.

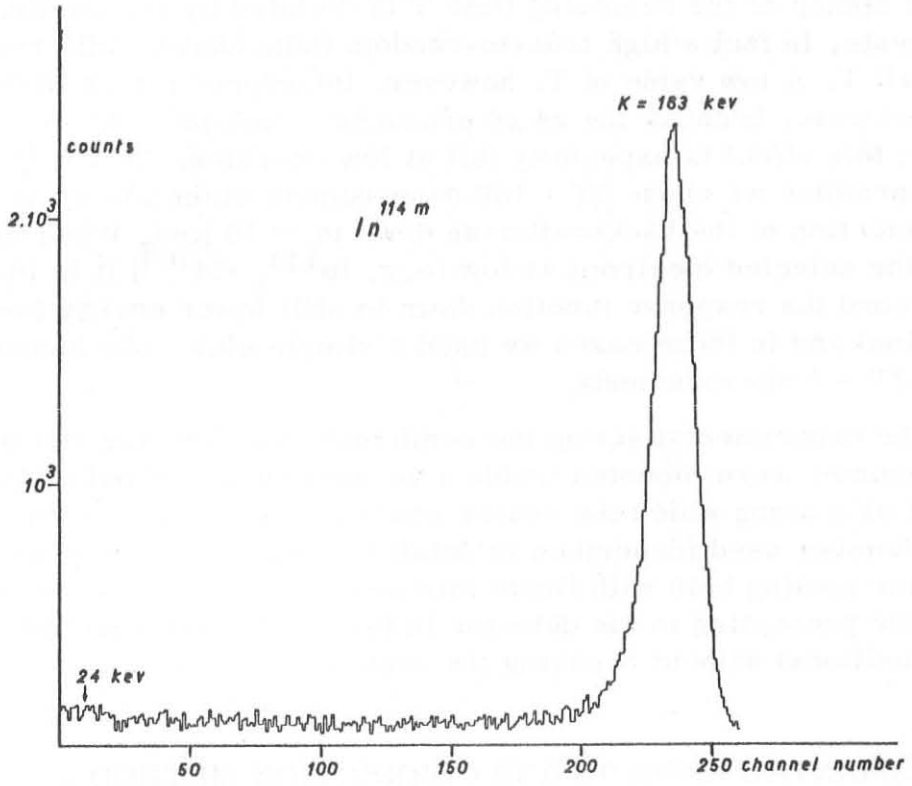

FIG. 2 - Response function for the 163 Kev electrons from 191 Kev isomeric transition in In^{114}. A slow coincidence circuit has been used for this measurement.

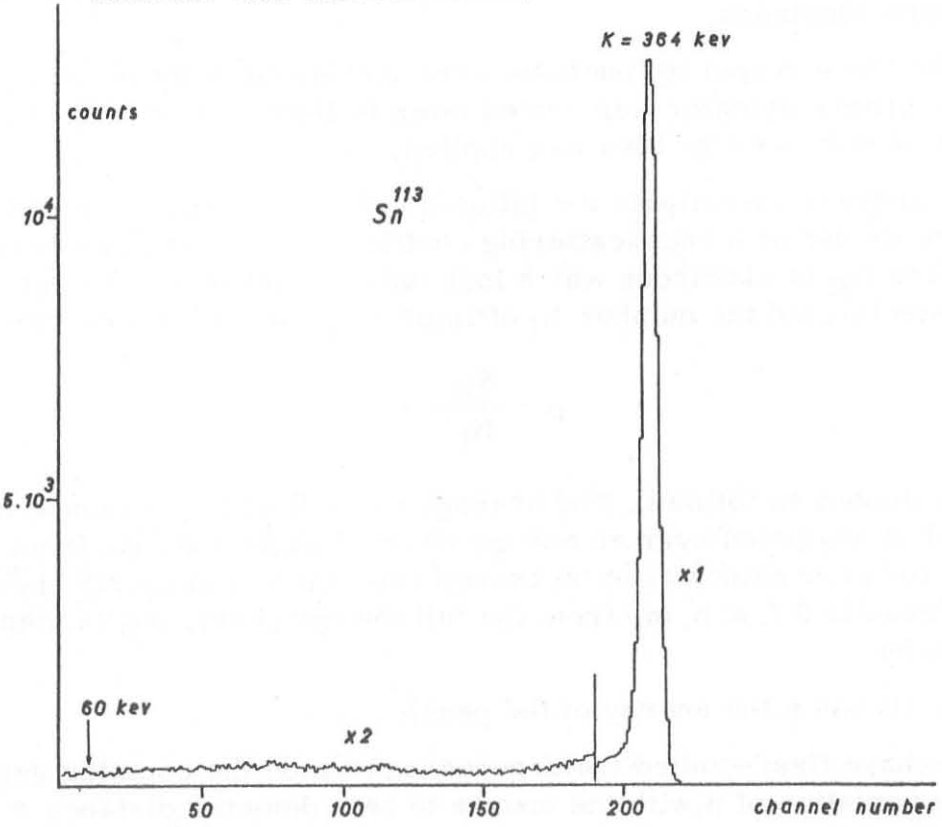

FIG. 3 - Response function for the 364 Kev electrons from the 392 Kev transition in the decay of Sn^{113}.

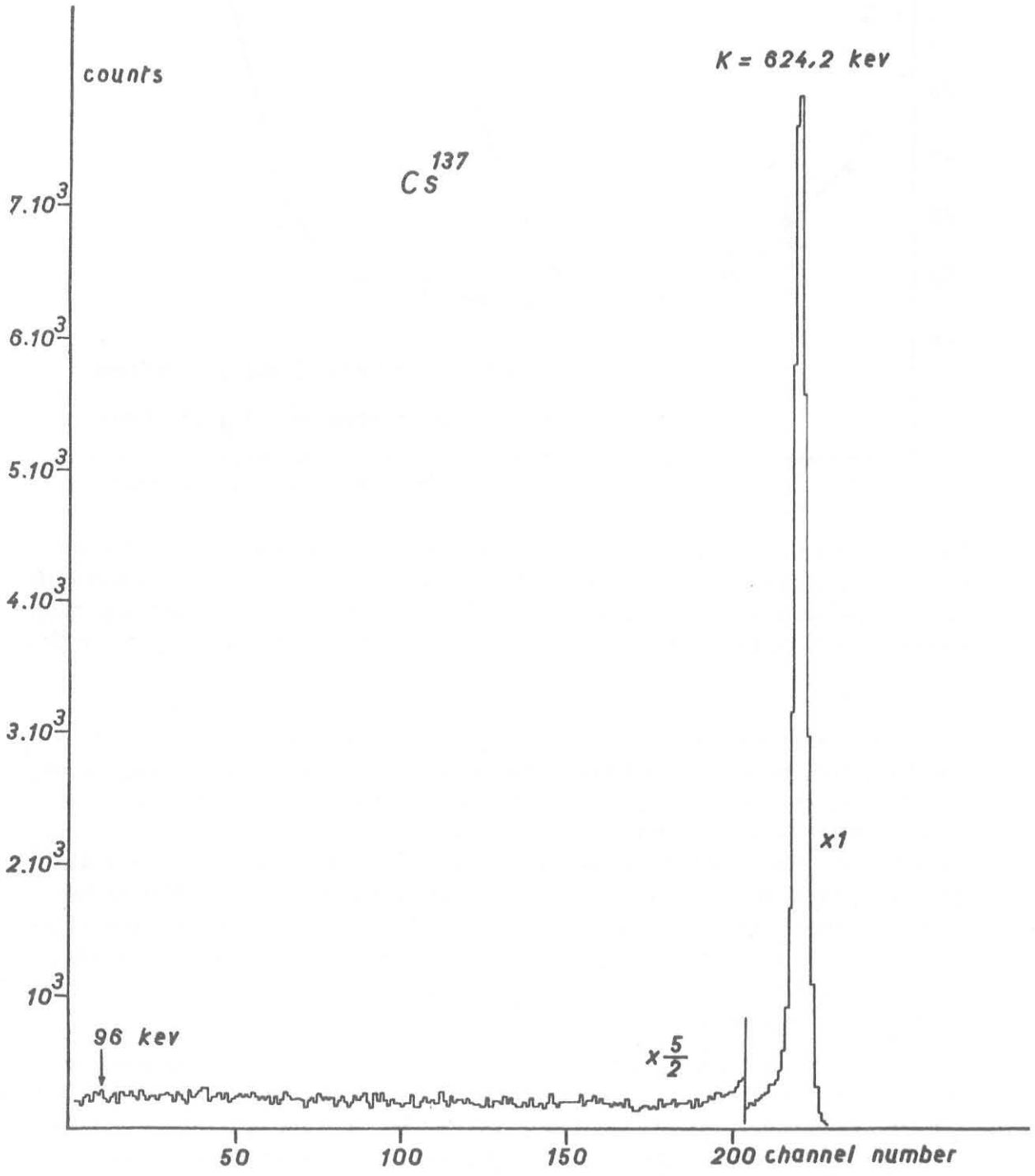

FIG. 4 - Response function for the 624 electrons from the 661 Kev transition in the decay of Cs^{137}.

The distance D of the semiconductor detector from the scintillator was kept costant in each run and the results are shown for two values of D.

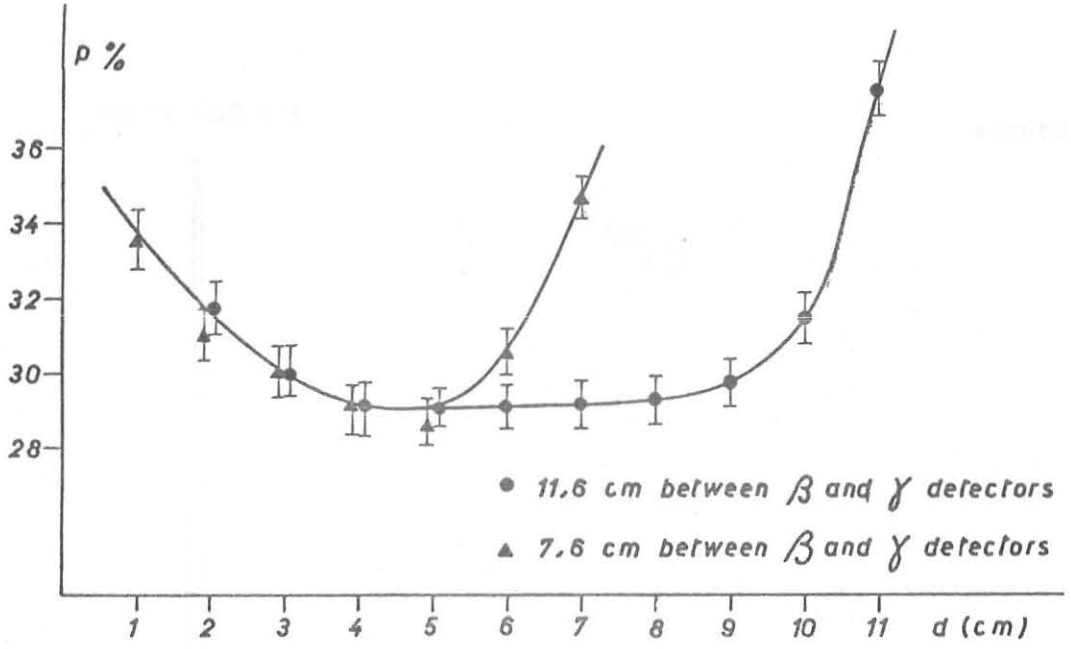

FIG. 5 - Typical trend of the backscattering coefficient p as a function of the source beta detector distance. The plotted data have been obtained with e_K-x coincidence measurements on a Sn^{113} source. The raise of the plot on the right side is due to the backscattering of electrons on the x ray detector.

Through the absolute value of p may change from a source to another (as will be discussed later) the general trend of the function p(d) is typical. It is apparent that the value of p has a minimum which becomes quite flat when the distance D is increased. The results can be reasonably interpreted as follows: as the distance d is increased (impinging angle decreases) p decreases and tends to a saturation value; when however the source comes near to the scintillation detector, this acts again as a sort of backscatterer and the value of p raises again. These results clearly emphasize the well known requirement to avoid small vacuum chamber dimensions in precision measurements.

If we now turn to the correction of (continuous) beta spectra it is clear that knowledge of the dependence of p on the energy is required. On the other hand this dependence cannot be studied unless the effects due to the source thickness are negligible. In fact we have observed that different sources of Cs^{137}, which were obtained with the method above described, even though they had similar transverse dimensions and comparable intensities showed differences up to 10% in their p values. Obviously these effects can be even more relevant when sources of different radionuclides are examined; in fact we could not obtain con

clusive evidence about the dependence, if any, of the coefficient p on the energy of incident electrons.

A typical series of p values obtained at a fixed geometry is given in Tab. I.

TABLE I

Source	Energy (KeV)	p
Cd^{109}	62	67,5%
In^{114m}	164	25,7%
Sn^{113}	365	26,6%
Cs^{137}	624	32,6%

On the other hand the data of K. Sen[7] obtained by selecting monoenergetic electrons with a magnetic spectrometer (thus avoiding any source effect) show only a slight variation of the coefficient p at least in the energy range 100 - 400 KeV, which is the more relevant part for our purposes.

It seemed to us therefore, that a correction of beta spectra for the backscattering effect could still be attempted on the basis of a p value indipendent of the energy of incident electrons, provided this value is measured for the same source even if only at a single energy. The results were encouraging and will be presently discussed.

We have adopted the well-known iterative correction method of Owen - Primakoff[8]; distorsion due to the finite resolution has not been taken into account since such distorsion turned out be negligible with our resolution (~ 10 Kev f.w.h.m.). This has been checked several times by inserting simulated spectra in the IBM - 1620 computer of the University of Florence. Figs. 6 and 7 show the experimental and corrected Kurie plots for beta spectra of Ce^{141} and Cs^{137}. Improvement in the linearity of the plot after correction is clearly apparent.

The correction method was also applied to spectra containing conversion lines and beta spectra together; the valueof α_K and α_K/α_{L+M} was evaluated both for the corrected and uncorrected spectra and the results are shown in table II. From examination of the data in table II the following remarks appear to be justified:

a) the evaluation of α_K from the ratio of the peak to the beta continuum is very much affected by the backscattering correction procedure; the correction improves very much the results, some of them coming very close to the generally accepted values;

b) the α_K/α_{L+M} ratio is much less sensitive to the correction (as it may be expected); both corrected and uncorrected values are not very far from "best" values but still, on the average, the corrected va

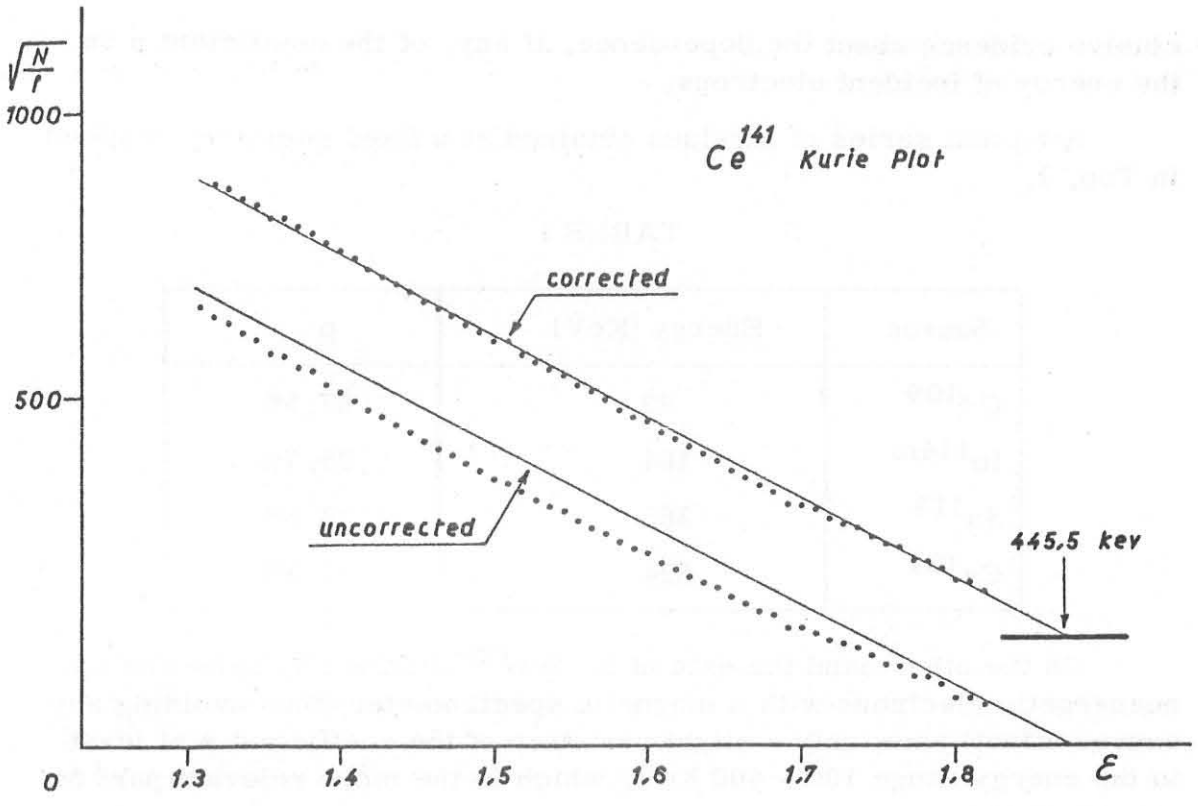

FIG. 6 - Uncorrected and corrected Kurie plot (p=30%) for the low energy beta spectrum of Ce^{141}.

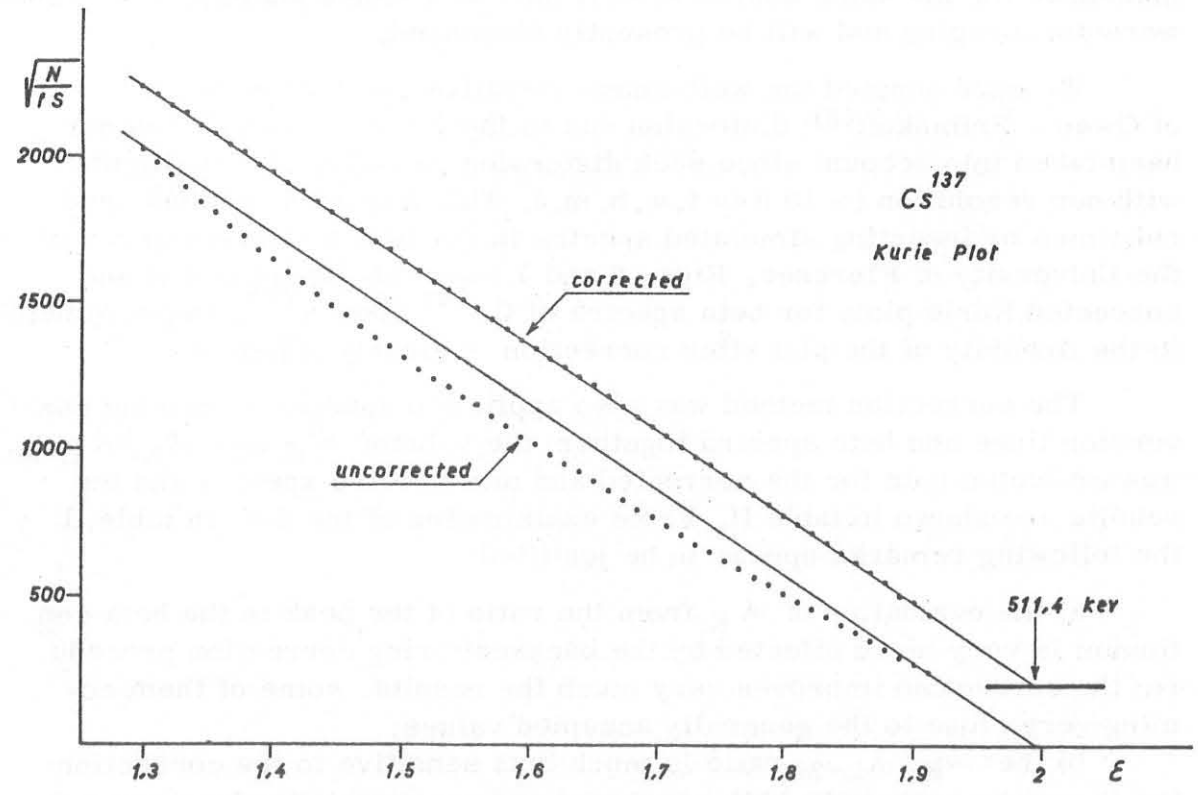

FIG. 7 - Uncorrected and correctedKurie plot (p=34%) for the low energy beta spectrum of Cs^{137}.

TABLE II

Detector	Source	UNCORRECTED VALUES				CORRECTED VALUES			DATA OF OTHER AUTHORS		
		E_f	$\alpha_k(x)$	$\frac{\alpha_k}{\alpha_{L+M}}$	p	E_f	α_k	K_{L+M}	E_f	α_k	$\frac{\alpha_k}{\alpha_{L+M}}$
1) ORTEC 2000	$Cs^{137(+)}$	502.6	0.078	4.33	34%	511.4	0.097	4.27	514 ± 2 [6]	0.0976 ± 0.005 [6]	4.50 ± 0.07
2) ORTEC 2000	Hg^{203}	200.2	0.114	2.74	40%	208.9	0.162	2.56	212 ± 1 [7]	0.163 ± 0.003 [8]	2.60 ± 0.06 [8]
3) ORTEC 2000	Hg^{203}	213.5	0.111	2.74	41%	210.7	0.159	2.62			
4) TMC 1000	Hg^{203}	224.9	0.129	2.75	31%	220.8	0.165	2.77			
5) TMC 1000	Hg^{203}	224.7	0.128	2.77	30%	225.9	0.165	2.76			
6) TMC 1000	Hg^{203}	221.3	0.145	2.52	30%	218.7	0.179 (o)	2.53			
7) TMC 1000	Ce^{141}	441.3 584.8	0.23	5.02	30%	445.5 585.7	0.17	5.03	432 ± 2 [9] 574 ± 3	0.22 [9]	6.35 [9]
8) TMC 1000	Ce^{141}	419.5 559.4	0.30	4.84	30%	430.8 565.4	0.29	5.36	440 ± 9 [10] 580 ± 5	0.34 ± 0.04 [10]	5.6 [10]

(x) - The area of the beta continuum is evaluated from the slope of the straight line (in the Kurie plot) best fitted to the data in an energy interval not containing conversion lines.

(+) - The high energy beta continuum has been subtracted.

(o) - We could not find any reasonable explanation for the large discrepancy of this datum.

lues give a better agreement.

c) the estimated end-point energy of a beta spectrum is not very sensitive to the backscattering correction; on the average, the correction seems to improve the agreement but uncertainties of different origin do not allow a definite conclusion on this point.

4) CONCLUSIONS -

At the present stage of the investigation the results support the following conclusions:

a) the backscattering coefficient on the detector, defined as above, for a given source, shows a typical behaviour as a function of the distance from the detector (see fig. 5); it reaches a "saturation value" for distances of the order of 4 times the detector diameter (provided no other backscatterer is present);

b) the value of p in somewhat variable from one source to another (say within $\pm$ 12% with the source preparation procedure adopted by us);

c) a simple iterative correction method (which assumes a constant response function for backscattered electrons) seems to be effective in improving Kurie plot linearity and relative intensity measurements (as for internal conversion coefficients) provided the value of p can be estimated for the same source used in the measurement (even for a single energy value).

We are grateful to Prof. M. Mandò for his constant encouragement and many helpful discussions.

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