DETERMINATION OF Cr-51 AND Fe-59 CONTAINED IN SAMPLES OF BIOLOGICAL MATERIALS — STUDY OF SOME TECHNIQUES

DETERMINAÇÃO DE Cr 51 e Fe 59 PRESENTES EM AMOSTRAS DE MATERIAIS BIOLÓGICOS — ESTUDO DE ALGUMAS TÉCNICAS

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Introduction

1 - In different situations, present in medical propedeutics, it is convenient and even necessary to employ, simultaneously, a tracer quantity of more than one radioisotope. This happens, for instance, when it is wanted to know, concomitantly, the iron plasma clearance, the percentage of iron utilization, the blood volume, the erythrocyte life span, the erythrokinetics,etc..And such situations became more frequent with the increasing use of radioisotopesin medicine[2,6,7,12,14]. Sometimes the patient has recently been submitted to a test with a certain radioisotope and it is necessary to make another one with a different radioactive tracer.

2 - The problem to be considered is essentially the following: there is a sample - which will be called "mixture" - containing a certain quantity X of a radioisotope R and X' of a radionuclide R', etc., and other samples - "standards" - containing, separately, the radioisotopes, R, R', etc., in aliquots of the administered doses. The determination of the fraction of the total activity corresponding to each radioisotope in the mixture could be made - at least in principle - if it were possible to repeat the sample and standards counting in as many different conditions as the number of the active components.

3 - Several techniques have already been given [1,4,5,8,9,10,11,12,13,14,15],for the determination of two and even more radionuclides present in samples of biological materials In nuclear physics this problem is not new and solutions have already been found for it since the Geiger-Muller counter was the only detector available. With the use of the scintillation counters and the pulse analysers the possibilities were increased. We are not going to discuss

at length this problem but only to present some techniques which we found useful during various experiments with samples containing Cr-51 and Fe-59. The techniques to be described are related to the following subjects·

a) determination of the sample radioactive decay,
b) use of absorber (filter),
c) use of pulse analyser,
d) use of atenuator (discriminator).

a) Determination of the sample radioactive decay

1 - The radioactive decay of a single radionuclide is given by an exponential law and the radioactive decay law of a sample containing two radioisotopes of different half-lives is obtained by adding two exponentials. For such a mixture, the counting rates obtained at successive times fall on a curve that,when plotted on a semi-logarithmic paper, can be decomposed into two straight lines.

2 - If the half-lives of the sample's components are known, it is possible to determine the contribution of each radioisotope to the total activity , from the countings realized in two different dates This is exactly what happens in the case of samples containing Cr-51 and Fe-59. The procedure is quite simple, but from its examination it will become clear thatit is not always practically suitable.

3 - Let us call T_1 the half-life of the Cr-51, T_2 the half-life of Fe-59, and $K_1 = 0,693/T_1$, and $k_2 = 0,693/T_2$ the respective desintegration constants . If in a certain time $t = 0$ the net counting (per unit time) of the sample is N_0, we can write,

$$N_0 = N_{01} + N_{02} \qquad (1)$$

N_{01} and N_{02} being the contributions of the Cr-51 and Fe-59 respectively. Repeating the counting after t days (in the same conditions, regarding the counting system and the geometry), it will be found another value N given by

$$N=N_{01}.e^{-k_1t} + N_{02}.e^{-k_2t} \tag{2}$$

From the equations (1) and (2) we can determine N_{01} and N_{02}:

$$N_{01} = \frac{N - N_0.e^{-k_2t}}{e^{-k_1t} - e^{-k_2t}} \tag{3}$$

$$N_{02} = \frac{N - N_0.e^{-k_1t}}{e^{-k_2t} - e^{-k_1t}} \tag{4}$$

4 - For the determination of N_{01} and N_{02}, the exponentials which appear in (3) and (4) must be calculated. Just to make it easier for the reader, we will indicate in table I the values of those exponentials for some values of t.

Table I

t - days	5	10	15	20	40
e^{-k_1t}	0,87955	0,77360	0,68042	0,59845	0,35814
e^{-k_2t}	0,92788	0,86096	0,79887	0,74125	0,54945
$e^{-k_2t} - e^{-k_1t}$	0,04833	0,0836	0,11845	0,14280	0,19131

5 - Using the expressions (3) and (4), the accuracy and precision of the values obtained are affected by the following factors: - a) the exactness with which the half-lives of the two radioisotopes are known; b) the stability of the counting system; c) the reprodutibility of the geometry in the countings; d) the precision with which the countings are made, e) the time elapsed between successive countings.

5a) The first factor gives a systematic error in the results, frequently the physician does not have the means to determine the half-life of a radioisotope with more exactness than the values found in the tables. Regarding Cr-51, the values found in table vary from 26,5 to 27,8 days: usually we consider its value as 27 days For the Fe-59, the values vary from 45 to 47,1 days, and we usually consider the value for its half-life as 46,3 days (Nuclear Data Sheet - N B.S)

5b)The stability of the counting system depends on the characteristics the system itself and of the working conditions (conditioned air, controlled humidity, continuous or discontinuous operation, etc.). This stability can be tested by counting in successive dates a sample of a radioactive material with a half-life sufficiently long (Cs-137, for example). In a general way, the long term stability of the counting systems at the physician's disposal is satisfactory enough for the aim we have at the moment.

5c) Regarding the scintillation heads with well-type crystal the reprodutibility of the geometry is, in general, very good and needs no discussion

5d) The counting precision depends on different factors, as the sample activity, background, time available for countings, etc . The standard deviation and the variation coefficient concerning to the observations are calculated from very well known equations [12,14], in which enter as variables the sample - counting time, the total number of counts accumulated in that time interval, as well as the time in which the background was registered and its total count

5e) Considering a given sample and a given standard deviation, there is a very strong influence of the time interval between countings on the precision of the results. As the time interval between the measurements is increased, the precision increases as well. In our case, the standard deviation for N_{01} is,

$$\sigma_1 = \sigma \frac{\sqrt{1 + e^{-2 k_2 t}}}{e^{-k_2 t} - e^{-k_1 t}} \tag{5}$$

and for N_{02} is,

$$\sigma_2 = \sigma \frac{\sqrt{1 + e^{-2 k_1 t}}}{e^{-k_2 t} - e^{-k_1 t}} \tag{6}$$

where σ is the standard deviation of the determination of N or N_0, when the measurements are made with equal precision. An analysis of equations (5) and (6) shows that for the time intervals equal to 10, 15, 20 and 40 days, σ_1 and σ_2 are related to σ by the following expressions: $\sigma_1 = 15,1\sigma$, $\sigma_2 = 14,5\sigma$; $\sigma_1 = 10,9\sigma$; $\sigma_2 = 10,2\sigma$; $\sigma_1 = 8,6\sigma$; $\sigma_2 = 8,2\sigma$; $\sigma_1 = 6\sigma$; $\sigma_2 = 5,6\sigma$.

Let us imagine an hypothetic mixture with a certain quantity of Cr-51 and Fe-59 so that we have for t=0, $N_{01} = 1250$ c/min; $N_{02} = 550$ c/min; $N_0 = 1800$ c/min and after 10, 15 and 20 days N is equal to 1441 c/min; 1290 c/min and 1156 c/min, respectively Suppose that those countings were made in a way as to give a standard deviation of 15 c/min. According to the initial counting and the one obtained on the tenth day, the coefficient of variation would be 18% for N_{01} and 39% for N_{02}. The counting realized on the 15th day would give 13,2% for N_{01} and 27,8% for N_{02}, and the one of the 20th day would give 10,3% for N_{01} and 22,4% for N_{02}. It can be noticed that the value of the coefficient of variation can be decreased by decreasing σ, that is, by getting a better counting statistics.

6 - The former observations show that the method which was described can give satisfactory results from the practical point of view, when there is no inconvenience in waiting a few days for doing the counting needed for the calculation of the final results; however, when the necessity arises of a quick diagnostic decision or when results with a small variance are required, the method should not be applied.

7 - As an example, we give in table II some results obtained with samples containing Cr-51 and Fe-59 in known proportions; in it the time interval between measurements was 40 days. In the same table, besides the calculated counting-rates are shown the values one should expect to obtain.

TABLE II

tube	1	2	3	4
Cr-51 calculated	1380 ± 90	2475 ± 90	5120 ± 90	735 ± 90
expected	1300 ± 15	2550 ± 15	5200 ± 15	675 ± 15
Fe-59 calculated	1195 ± 84	2578 ± 84	5022 ± 84	553 ± 84
expected	1250 ± 15	2510 ± 15	4950 ± 15	620 ± 15

8 - The procedure indicated above for studying the sample decay can be changed: instead of restricting ourselves to measurements in two predetermined times, a series of measurements can be made either in consecutive or alternate days and from these data the values of N_0 and N_{02} can be calculated by the least square

method. Although the calculations are rather lenghty the results obtained are better; in practice a decision between the methods described above should be made taking into account the availability of time for calculations, but usually the first method is good enough.

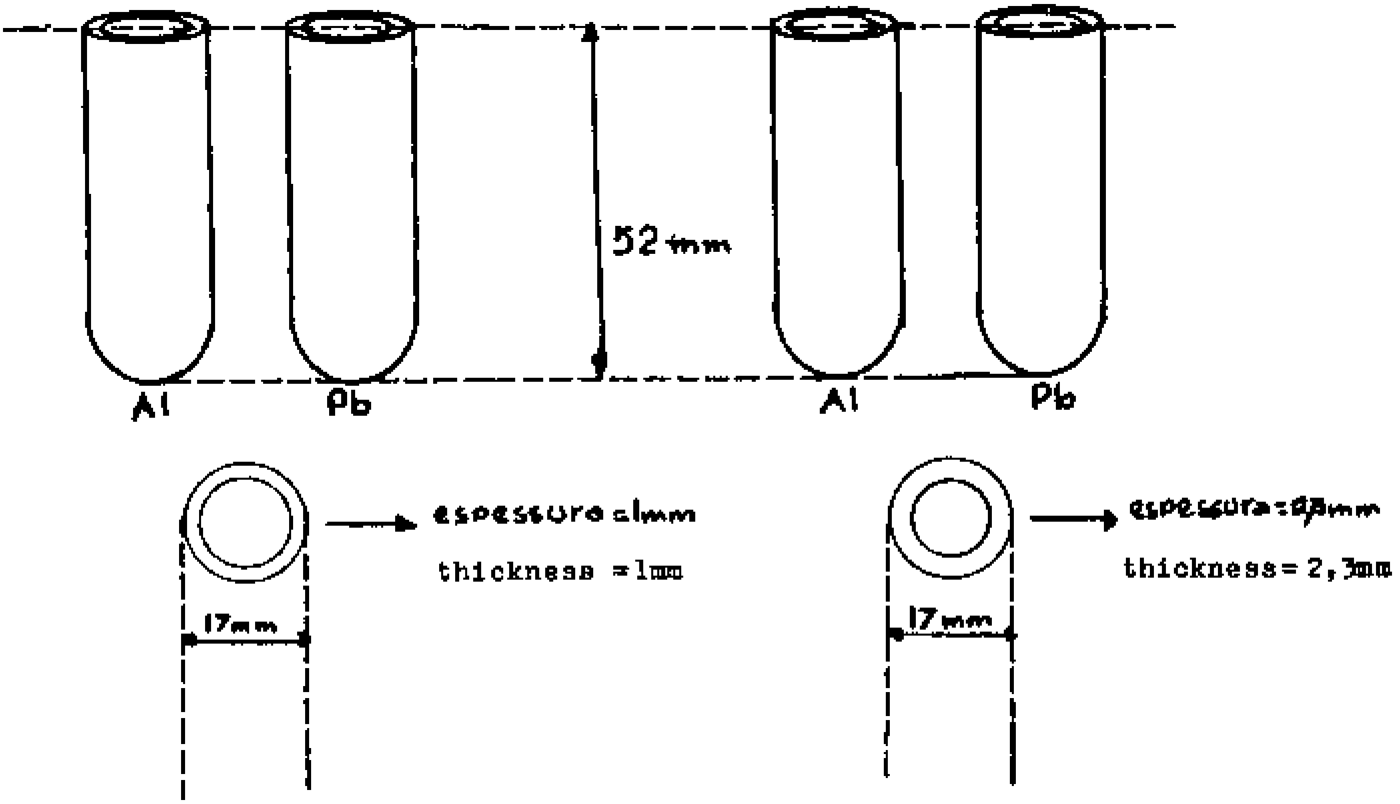
b) Use of absorber (filter)

1 - The absorption coefficient of any material is a function of the radiation energy. Since Cr-51 gives a gamma radiation of 320 keV, while those of the Fe-59 have more than 1 MeV, the lead absorption coefficient has very different values for such radiations. This result can be used to evaluate the fraction of the activity, in a mixture of Cr-51 and Fe-59, which is due to each isotope Libby et al.[9] were the first ones to suggest the use of a lead absorber for the analysis of biological samples, containing the above radionuclides, when a scintillation detector is used.

2 - When a crystal well detector is used the absorber must be a cylinder of uniform thickness surrounding all the region of the sampling tube which is inserted in the well. Two measurements should be made: one with and one without absorber In order to keep the same geometry Libby has suggested the use of a wooden support with the same dimensions as the lead filter. In our measurements we have used an aluminium support which has the advantage of being stiffer and lasting longer, besides being easily decontaminated in case of an accident

3 - In fig 1 two filters and the corresponding supports which were used in our measurements are sketched

FIG I



The thickness of the first one was 1 mm and of the second 2,3 mm. It should be noticed that the dimensions of the filter are related to those of the well and the counting tubes used.

4 - The first step must be to determine the relation between the total counting-rates which are obtained for samples containing only Cr-51 and only Fe-59 when using the absorber, and when using the support. Once those relations are known, they can be used for any determination which uses the same counting system and the same filter and support Let n_{01} be the net counting-rate of

the Cr-51 sample measured with the support and let $K_1 . N_{01}$ be the result for the same sample when a filter is used and the measurement is made in the same time interval Let N_{02} and $K_2 . N_{02}$ be the corresponding counting-rates for the Fe - 59 sample All those measurements should be made in such a way that the statistical errors are small since the variances for K_1 and K_2 will be given by the sums of the variances related to the counting-rates from which the above coefficients are calculated

5 - Let us suppose the net counting-rate of a sample containing Cr-51 and Fe - 59 be n_0 when obtained with support and n when obtained with filter. We can write

$$n_0 = n_1 + n_2 \tag{7}$$

$$n = K_1 . n_1 + K_2 . n_2 \tag{8}$$

where with n_1 and n_2 we represent the unknown counting-rates corresponding, respectively, to Cr-51 and Fe-59, when measured with the support From the above equations we get the following expressions for n_1 and n_2:

$$n_1 = \frac{n - K_2 n_0}{K_1 - K_2} \tag{9}$$

$$n_2 = \frac{n - K_1 n_0}{K_2 - K_1} \tag{10}$$

6 - For the first pair (filter and support) used we got K_1 = 0,5255 and K_2 = 0,8848 with $|K_1 - K_2|$ = 0,3593 For the second, the values were K_1 =0,3557 and K_2 = 0,8317, with $|K_1 - K_2|$ = 0,4760.

7 - The accuracy and precision of the results obtained by this technique is influenced by several factors amongst which the most important are: a)the accuracy with which K_1 and K_2 were measured, b) the precision of the countings; c) the reprodutibility of the geometry; d) the difference between K_1 and K_2.

7a) The accuracy with which K_1 and K_2 is known depends on the measurements which were made for their computation Once the values for those coefficients are fixed, their errors will determine a systematic error in the results. One should observe that the error with which those coefficients can be obtained is smaller than errors due to the uncertitude in the half-lives.

7b) The problem of the precision of the measurements is similar to the one which has already been considered in the case of a radioactive decay and there is nothing else to add to what has already been said.

7c) The reprodutibility of the geometry depends on the good construction of the filter and support and there is no problem if both have equal dimensions.

7d) The precision of the calculated values of n_1 and n_2 depends strongly on the differences between the values of K_1 and K_2 Supposing K_1 and K_2 with fixed values, the standard deviation for n_1 will be expressed by:

$$\sigma_1 = \sigma \frac{\sqrt{1 + K_2}}{|K_2 - K_1|} \qquad (11)$$

and for n_2 by:

$$\sigma_2 = \sigma \frac{\sqrt{1 + K_1}}{|K_2 - K_1|} \qquad (12)$$

where σ is the standard deviation of the sample countings. For our first pair we have $\sigma_1 = 3,8\,\sigma$ and $\sigma_2 = 3,4\,\sigma$; for the second one $\sigma_1 = 2,7\,\sigma$ and $\sigma_2 = 2,4\,\sigma$. It is not practical to increase more the filter thickness unless a crystal with a larger diameter is available. Indeed, for a given well diameter any increase of the thickness of the filter will also reduce the counting efficiency, as long as the sample volume is maintained constant. Consequently, the counting time must be increased in order to reduce the statistical error to a convenient value For use with a normal crystal a filter of 1,5mm of thickness gives satisfactory results, from the practical point of view.

8 - As an example we give in table III the results obtained with this technique, for the counting rates corresponding to Cr-51 and Fe-59, in samples of known composition, and using the first pair of filter-support

Table III

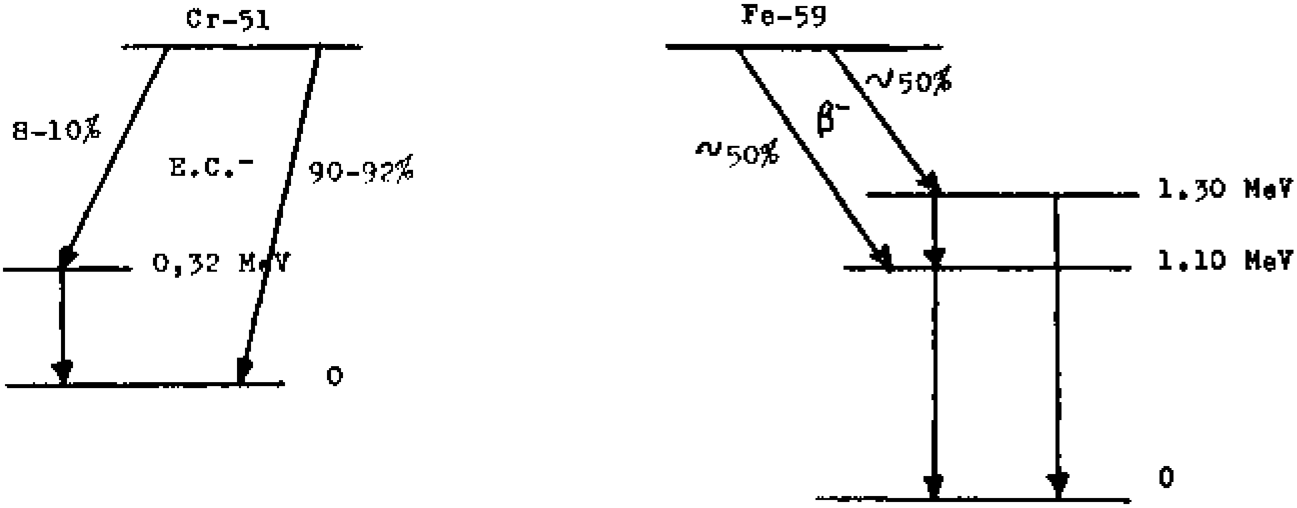
tube	1	2	3	4
Cr-51 calculated	1091 ± 57	2189 ± 57	632 ± 57	4323 ± 57
expected	1050 ± 15	2150 ± 15	580 ± 15	4350 ± 15
Fe-59 calculated	1153 ± 51	2388 ± 51	609 ± 51	4943 ± 51
expected	1200 ± 15	2420 ± 15	650 ± 15	4900 ± 15

8.1 - It is important to notice that the variations coefficients are much smaller than the corresponding ones in Table II, even with N_{01} and N_{02} being of the same order of magnitude.

c) - Use of the pulse analyser

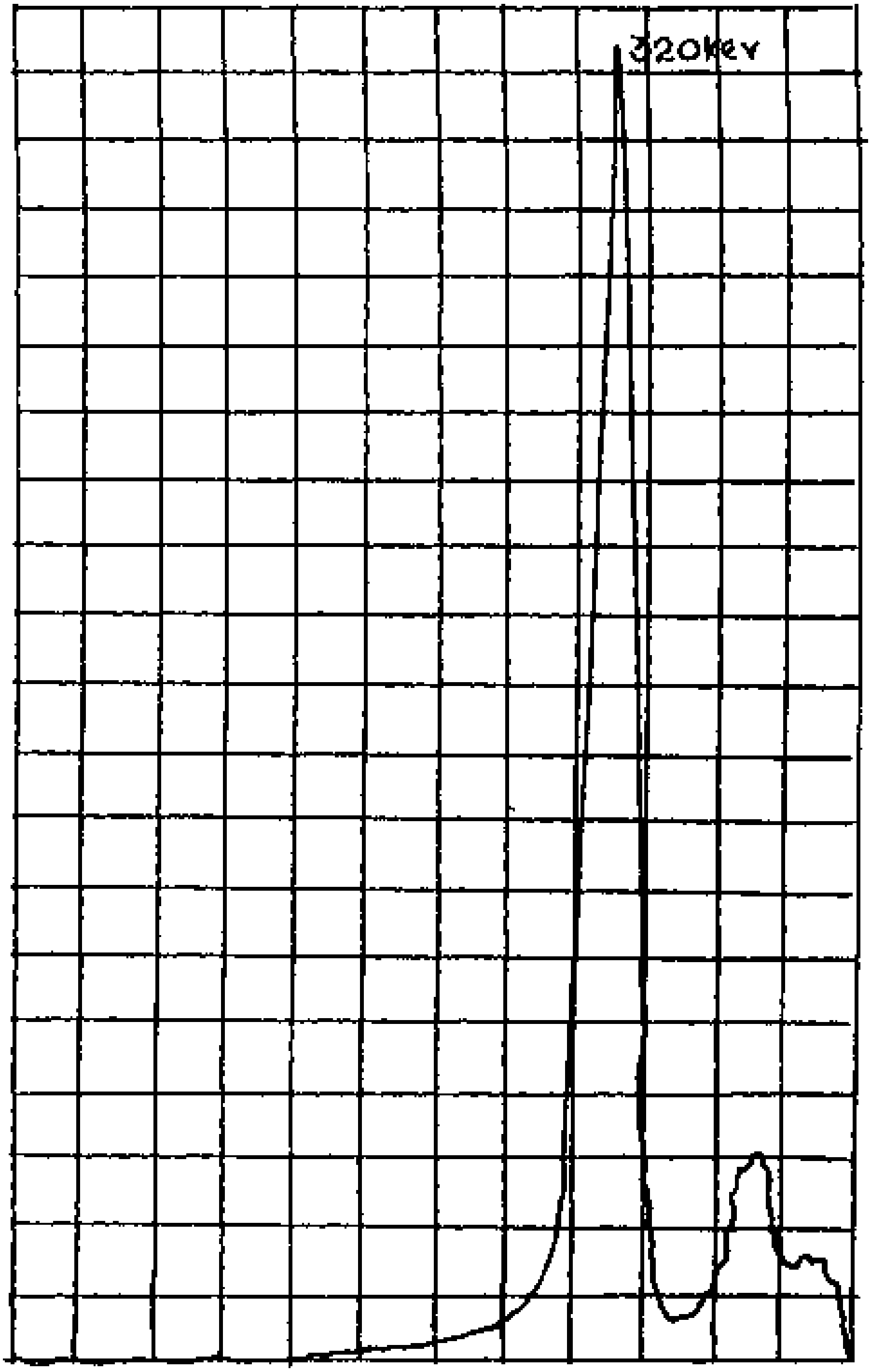
1 - It is well known that the scintillation counter gives pulses whose heights depend on the energy of radiation absorbed in the crystal, in contrast to what happens with a Geiger-Muller counter. Due to this circumstance it is possible, using a pulse analyser, to separate different energies. Now, the shape of the gamma radiation spectrum is characteristic of each radionuclide that emits gamma rays. It is then possible to identify the radionuclides, using a method that is, in principle, similar to the method used in optical spectrometry for the identification of elements. This identification of the radionuclides by the gamma ray spectrum is made using a pulse analyser and a scintillation counter. There are many different kinds of pulse analysers of one channel. They can be used with different techniques that we are not going to discuss at the moment. Let us remember only that, by varying the base and keeping fix the window, it is possible to get a gamma spectrum of the sample. Fig. 2 gives the desintegration schemes of Cr-51 and Fe-59, fig 3 gives the gamma spectrum of Cr-51 and fig 4 the one of Fe-59, both obtained with a medical spectrometer.

Fig 2



Desintegration schemes of Cr-51 and Fe-59

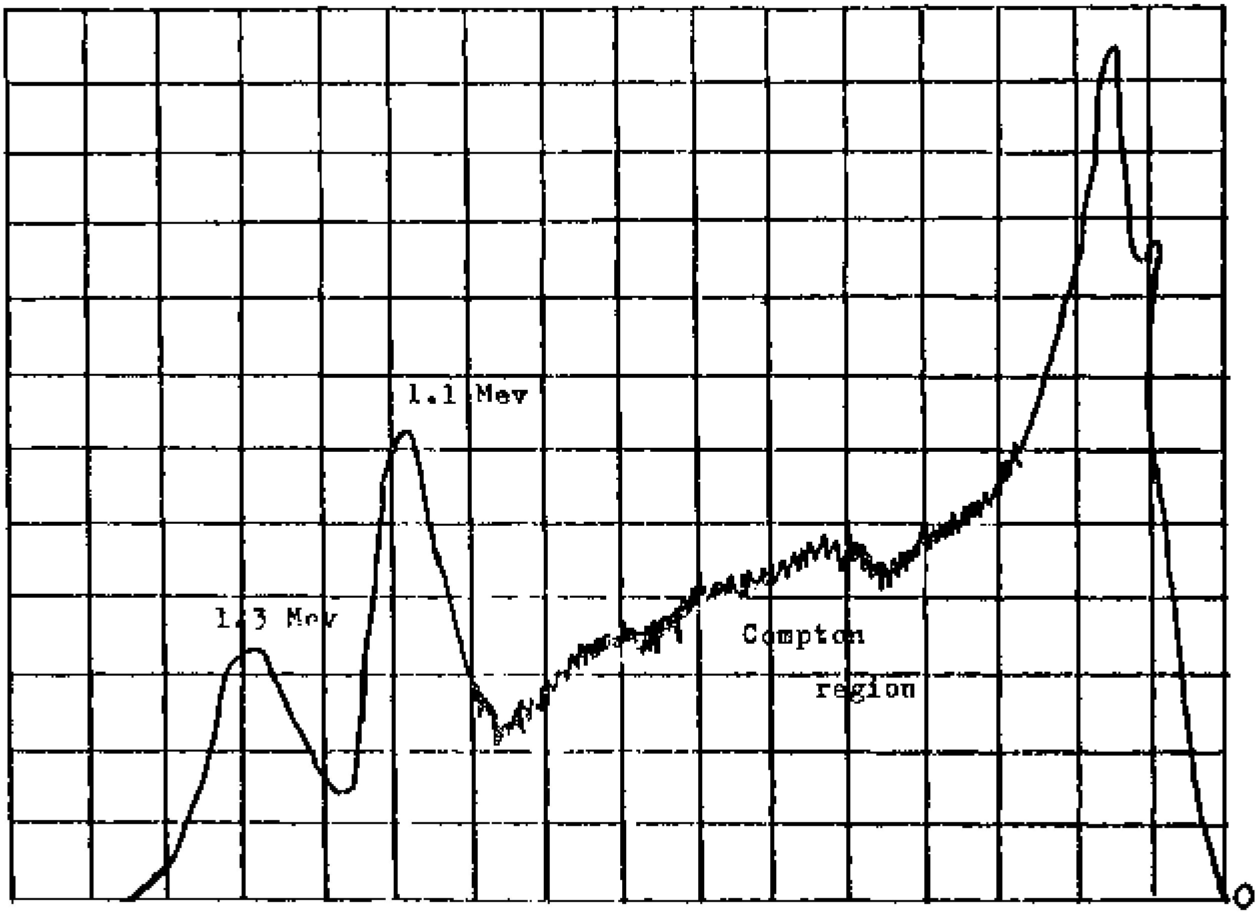
Fig. 3



Spectrum of Cr-51

2 – An examination of the gamma spectrum of Cr-51, for example, shows that at the low energy end there is a region of continuously decreasing counting rate, followed by a photopeak at 320 keV. The gamma radiations responsible for the appearance of that region do not come directly from the desintegration of Cr-51 but owe their origin to the so called Compton effect. For this reason, that region is called Compton continuum or Compton region On the other hand we can observe that above the region in which appears the photopeak of 320 keV there are no more counting rates that can be attributed to the presence of Cr-51 what we count is only the background radiation.

Fig 4



Spectrum of Fe-59

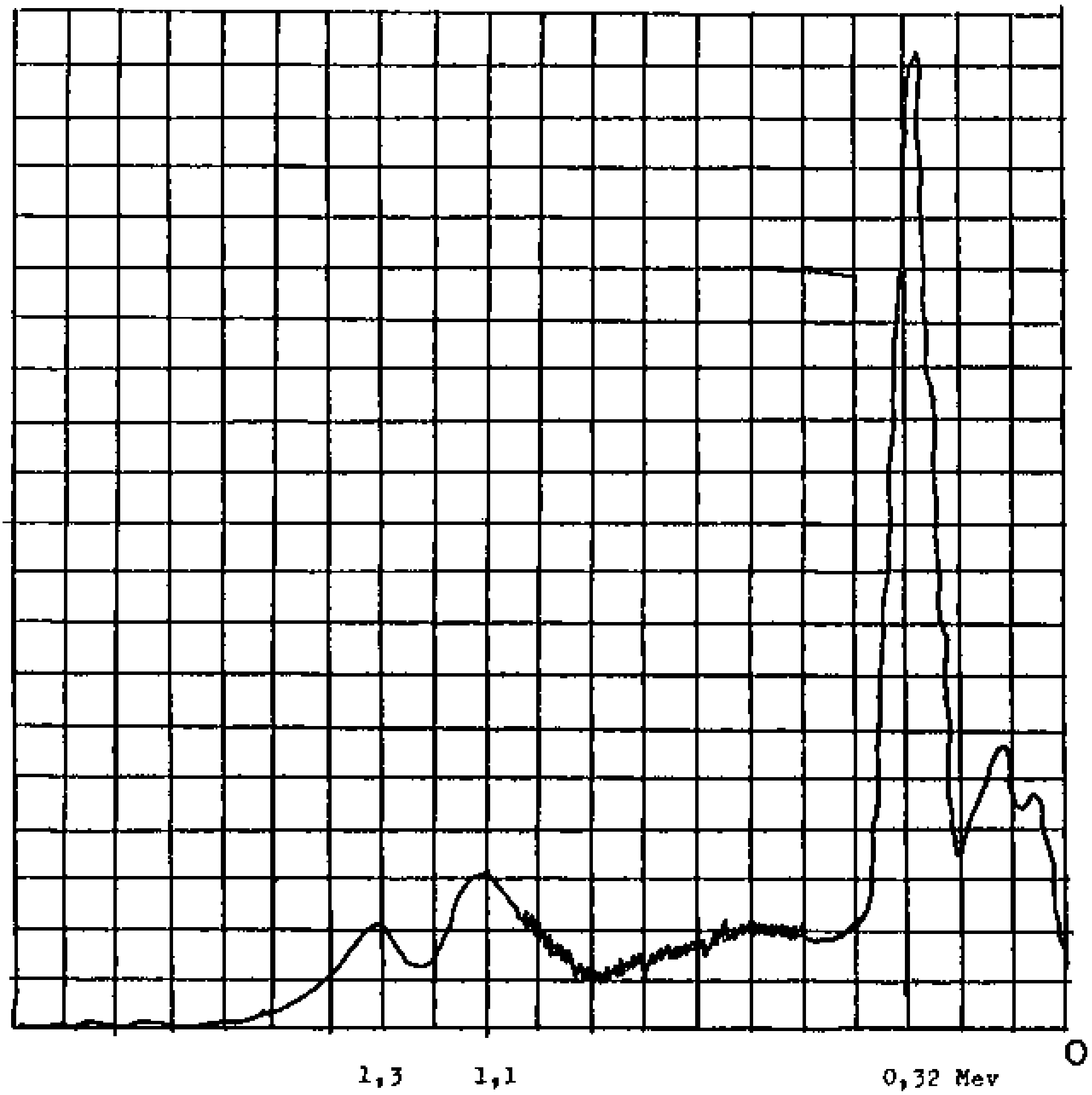
3 - If we compare the spectrum of Fe-59 with that of Cr-51, we can notice that the peak of the Cr-51 is in the Compton continuum of the spectrum of Fe-59. Thus, in a mixture of Cr-51 and Fe-59 the counting rates on the regions of 320 keV, will result from the contribution of the Cr-51 plus the Compton continuum due to the radiations given by the Fe-59. Fig 5 shows the spectrum of a mixture of Cr-51 and Fe-59.

4 - When we examine a sample containing Cr-51 and Fe-59 the countings at the photopeak of the Cr-51 depend on the Compton continuum due to Fe-59 but the countings at the photopeak of Fe-59 are not influenced by the Cr-51.

4 1 - Notwithstanding this interference between the photopeak and the Compton continuum, the analysis of such a sample can be easily made, due to the fact that the gamma-ray energies are quite different and the half-lives are large compared with the counting times If we had the Cr-51 and the I-131 (studied by Adams et al [1,2]) or radionuclides of half-lives of the same order of the counting times, the problem would be more complex [10].

5 - The procedure adopted in the case of the mixture of Cr-51 and Fe-59, was the following - A sample of Cr-51 was taken and the corresponding photopeak carefully located The base level was then increased till the value that reduced the counting rate to the background. That sample was then substituted by another one containing only Fe-59. A first counting was made on the photopeak of Cr-51 , and a second one changing the base to the level previously established and opening the window completely Calculating the net counting rates, and dividing the first by the second, we get a factor, which we indicate as <u>k</u>, and by which we can estimate the contribution of the Fe-59 to the counting at the photopeak of Cr-51 when we have those two radioisotopes When we have a sample containing Cr-51 and Fe-59 two countings are made, in the same conditions as indicated for the one con

Fig. 5



Mixture of Cr-51 and Fe-59

taining only Fe-59. So we can write:

$$N_1 = N_{Cr} + kN_{Fe} \tag{13}$$

$$N_2 = N_{Fe} \tag{14}$$

where N_1 and N_2 are the net counting obtained and N_{Cr} and N_{Fe} are the parcels corresponding to the Cr-51 and Fe-59, respectively. From the above expression we get

$$N_{Fe} = N_2 \tag{15}$$

$$N_{Cr} = N_1 - k.N_2 \tag{16}$$

6 - The following factors, besides others, are responsible for the accuracy and precision of the results a) the accuracy with which we determine k;b) the stability of the equipment employed; c) the precision with which the countings are made

6a) In order to have k with a good accuracy it is necessary that it be determined from countings with small statistical errors. It is also convenient that the sample of Cr-51 used for the determination of the photopeak have an activity not too different from the one expected on the samples to be counted. This applies also for the sample of Fe-59. This precaution must be taken because the height of the impulses given by the photomultipliers of common use (as the Dumont 6292), depends on the counting rates, specially when these are high [3] Once k has been determined the error it will induce in the results will be a systematic one. As long as the equipment conditions are maintained, k will not be altered , but it is always convenient to determine k on the day the samples are counted.Once k has been found, and supposing the countings were made with the same standard deviation σ , the standard deviation σ_1, referring to N_{Cr} will be given by

$$\sigma_1 = \sigma\sqrt{(1 + k^2)} \tag{17}$$

As an example, with our equipment it is frequent to have $k = 0{,}177$ and so

$$\sigma_1 = 1{,}1\sigma$$

7 - Table IV shows some results obtained with samples containing Cr-51 and Fe-59, in known quantities, and using the pulse analyser

Table IV

tube	1	2	3	4
Cr-51 calculated	2002 ± 16	3980 ± 16	1010 ± 16	6130 ± 16
expected	1985 ± 15	4000 ± 15	1015 ± 15	6100 ± 15
Fe-59 calculated	1478 ± 15	3045 ± 15	825 ± 15	4592 ± 15
expected	1500 ± 15	3020 ± 15	805 ± 15	4620 ± 15

7.1 - From these data, we can see that the variance is smaller now than for the former procedures, with the same value for the statistical error

8 - The procedure indicated for the use of the pulse analyser in measurements of mixtures containing Cr-51 and Fe-59 is easier than that indicated by Weinstein et al [13,15] However, their techniques would be successful if the Cr-51 had gamma radiations with energies similar to those of the Fe-59; but this is not the case

d) - Use of atenuator (discriminator)

1 - Due to the photopeak of Cr-51 being far from those of Fe-59 it is possible to analyse the mixture of those radionuclides with methods simpler and more economic than that using a pulse analyser.

1 1 - An atenuator (or a discriminator) such as the ones that can be found on many counting systems, will be sufficient to obtain the desired results The atenuator works almost as the low level discriminator or base of the pulse analysers; it allows the electronic counter to receive only pulses which have a height equal or greater than a pre-fixed level; and this height can be varied between limits more or less amples.

2 - If the atenuator has been well adjusted, the pulses from the radiations given by the Cr-51 will not be counted or only counted partially When - there is a mixture of Cr-51 and Fe-59, a large fraction of the pulses from the Compton continuum produced by the radiation of Fe-59 will obviously not be counted as well. A counting of such mixture will give a result which will depend solely on the amount of Fe-59 present. On the other hand, the countings made with the discriminator on its lowest level, will give a result due to the total amount of radionuclides present. If we count on the same conditions a sample containing only Fe-59 we will, then, be able to get the desired result.

3 - The procedure usually employed is the following:

3 1 - A sample containing only Cr-51 is put in a counting tube and this in a well type crystal. The atenuation factor (or discriminator level) is carefully adjusted until the counting rate is reduced to the background value (for the discriminator setting used).

3 2 - The Cr-51 sample is then substituted by one containing only Fe-59. Let $N' = K.N_o$ be the net counting with the atenuator on the chosen position and N_o the net counting with the atenuator at its minimum level. The quotient of both countings will allow to determine **K**. This value for K represents the fraction of pulses from the samples of Fe-59 that are counted when the atenuator is in a level which eliminates completely the countings due to Cr-51.

3 3.- To know the composition of a given mixture we proceed as follows N_t being the net counting when the atenuator is at its minimum level, and N_p being the net counting when the contribution of Cr-51 is discounted, we can write:

$$N_t = N_{Cr} + N_{Fe} \tag{18}$$

$$N_p = K.N_{Fe} \tag{19}$$

where N_{Cr} is the counting due to Cr-51 and N_{Fe} the one due to Fe-59. From the above equations we have

$$N_{Fe} = (1/K).\ N_p \tag{20}$$

$$N_{Cr} = N_t - (1/K)\ N_p \tag{21}$$

4 - The accuracy and precision of these results depend principally on the following a) the accuracy with which **K** is determined; b) stability of the equipment employed, c) precision with which the countings are made, etc.

4a) Since **K** is the quotient of two countings, the accuracy by which it can be obtained depends on the countings statistical errors and on the stability of the counting system. Once **K** has been fixed, the error with which it was obtained will be a systematic one As long as the equipment conditions are the same, K will not be altered However, it is always convenient to repeat its determination at the begining and end of a series of measurements. Once K is obtained, the errors propagation law makes it possible to obtain the standard deviation due to N_{Cr} and N_{Fe} We have

$$\sigma_{Fe}^2 = \frac{\sigma_t^2}{K^2} \tag{22}$$

$$\sigma_{Cr}^2 = \sigma_t^2 + \sigma_p^2 \quad \frac{1}{K^2} \tag{23}$$

where σ_t, σ_p, σ_{Fe} and σ_{Cr} are the standard deviations relatively to N_t, N_p, N_{Fe} and N_{Cr}, respectively. The smaller K is, the greater will be the error in determining N_{Cr} and N_{Fe}; then, it is desirable that the position chosen for the atenuator be one such as to cut as little as possible the pulses of Fe-59, with energies above Cr-51

5 - Table V gives the results which were obtained using a Philips counting system Using only the atenuator, it was found that in the position 10 x 2 the counting of a sample of Cr-51 was reduced to background It also shows the results obtained with a sample of Fe-59 and of a mixture of Cr-51 and Fe-59.

Table V

sample	atenuator	c/min	Bkg c/ min	net counting
Fe-59	1 x 1	17896	638	17258
Fe-59	10 x 2	2442	55	2387
Cr-51 + Fe-59	1 x 1	17073	638	16435
Cr-51 + Fe-59	10 x 2	1955	55	1900
K = 0,138				

Final illustration

1 - In the following table we give some results calculated by the techniques described and corresponding to a series of blood samples taken from patients who received Cr-51 and Fe-59 The results were "normalised" by the first one obtained with the pulse analyser, in order to make easier the comparison. The time interval in the decay technique was 40 days.

Table VI

Cr-51	I	II	III	IV	V	VI	VII	VIII
Decay	2697	2710	2587	2286	1971	1689	1345	1389
Absorber	2697	2650	2590	2315	2056	1854	1397	1303
Analyser	2697	2666	2565	2330	2039	1823	1429	1281
Atenuator	2697	2649	2551	2321	2041	1816	1443	1290

Fe-59	I	II	III	IV	V	VI	VII	VIII
Decay	1177	2646	4470	4785	5715	4771	4468	4685
Absorber	1177	2697	4401	4772	5620	4798	4413	4726
Analyser	1177	2689	4419	4741	5660	4826	4395	4794
Atenuator	1177	2671	4427	4745	5645	4803	4382	4809

CONCLUSIONS

1 - We can observe that the best results for mixtures containing Cr-51 and Fe-59, are obtained using the pulse analyser This analyser presents the inconveniences of being expensive, of difficult maintenance, and of needing assistance of highly qualified technicians From a practical point of view, and as

far as the analysis of the mixture of Cr-51 and Fe-59 are concerned, the pulse analyser can be substituted by the atenuator, (discriminator) which is generally found in most of the electronic counters available for sale.

If even the atenuator is not available, an absorber can be used. Finally the analysis of the radioactive mixture decay gives rise to large errors, and being a time consuming technique does not give results at short time.

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