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by

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# WEAK TRANSITIONS IN $^{44}Ca$

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## 1. INTRODUCTION

Low lying excited states in $^{44}Ca$ have been the object of extensive investigations(1, 3, 6, 7, 13, 18, 22); nevertheless many obscure points remained up to now. Most conspicuous among them seem to be the difficulties in assigning experimentally the feeding channel to the first $0^+$ - 1885 kev level. The very existence of that level has been clearly demonstrated first through the work of Lawley et al(7) and Martin et al(8) on inelastic proton scattering off $^{44}Ca$ but the bulk of experimental work is quite controverse as to its population channel from other levels in $^{44}Ca$ or from beta decay of $^{44}K$ and $^{44}Sc$. Gamma rays connecting the states $0^+$ - 1885 kev and $2^+$ - 1157 kev have been quoted by Sugiyama et al(1) and Levkovskii and Kazachevskii(2), following beta decay of $^{44}K$, and by McCullen and Kraushaar (3), following the decay of $^{44}Sc$, but have not been detected by Taylor et al(4) in similar investigations. Neutron capture gamma rays observed in $^{44}Ca$ by Arnell et al(5) and more recently by White and

Birkett[6] have also displayed that transition but with no references to its connections to other levels in $^{44}$Ca. Another questionable point is the existence of a level at about 2850 kev; evidence has been found by King et al[9], Dillman and Kraushaar[10] and denied by other authors above mentioned[11]; however a possible analogue level in the cross-conjugated partner $^{52}$Cr has been found in p, p', experiments by Monahan et al[12].

The fairly good success of theoretical calculations in the (f7/2) shell stems partly from filling in the most evident omissions of the assumption of pure, f7/2 configurations in the seniority coupling scheme with calculations involving core excited configurations. In particular the 1885kve level in $^{44}$Ca is only obtained through excited core manipulations [13,14,15,16,17] and the one at 2850 kev is predicted in the seniority coupling scheme[18] with $\nu$=2. The wave function of the 1885 kev level turns out to have a strong mixing of other orbitals besides $\ell$=3, which allows for a possible beta branching from the $2^+$ ground state of $^{44}$Sc. On the other hand,the purity of seniority states in $^{44}$Ca has been questioned several times[7,19,20,21,23]; however a $J^\pi=5^+$ $\nu$=4 should be a pure one since no other $5^+$ state is available to the $(f7/2)^4$ configuration with T=2. It is therefore quite surprising that such a level has not been found in $^{44}$Ca, while its counterpart in $^{52}$Cr has been long since identified[12].

With those prejudices in mind we decided to look closely into the beta decay of $^{44}$Sc once again.

## 2. OBSERVATIONS

Samples of ScO, 99.99% purity were irradiated with the bremsstrahlung beam of the electron Linac of this institute, both at 22 MeV and

28 MeV. The activity of $^{44}Sc$ has been followed through the life-times of its ground state and $6^+$ isomeric state, by means of the annihilation radiation and the 271 kev gamma transition connecting those levels. The source material has been kept in a 0.1 mm thick aluminum container, which was responsible for a spurious activity of $^{24}Na$, formed by $^{27}Al(\gamma,{}^3He)^{24}Na$(Q=23.709MeV) in the irradiations at 28 MeV; small amounts of $^{42}K$ activity, formed by $^{45}Sc(\gamma,{}^3He)^{42}K$ (Q=20.976 KeV) have also been observed. No other spurious activities have been induced.

Singles and coincidence spectra were observed both with Ge-Li and NaI(Tℓ) detectors. The former were 18cm³ active volume ones, 3 kev resolution at the higher energy $^{60}Co$ line and the last ones 3" x 3", 8% resolution at the $^{137}Cs$ line. Singles spectra were taken to fix overall features. Coincidence spectra were used mainly to avoid pile-up from the annihilation radiation; since the bulk of annihilation events occurred in the source container, arrangements such as that in fig. 1 were adopted throughout for that purpose. To enhance the detection probability for the 728 gamma rays special runs were done, with the MCA gated by the 1157 kev, $2^+ - 0^+$ gamma rays, and the input open to the range 530 kev $\leq E_\gamma \leq$ 1000 kev. Coincidence spectra have all been taken one day after irradiation, on the average.

Calibration energies were obtained with a set of gamma ray sources up to the energies of the $^{24}Na$ lines and the experimental points were used to fit a best line among them (fig.2). Relative intensity estimates were based upon the curve of photopeak efficiency for one of the Ge-Li detectors with the same set of standard sources, referred to above, up to the sum peak of $^{60}Co$ Lines (fig.3); the area under the peaks was obtained by means of a computer program which subtracts background through a best straight line procedure. Results are shown in Table I; sample spectra are shown in figs. 4, through 9.

3. RESULTS AND DISCUSSION

In addition to other well known transitions in $^{44}Ca$, gamma rays at 564 kev and 728 kev have been detected.The positions of all those lines in the level scheme of $^{44}Ca$ are shown in figs. 6, 7, 8, 9, where energies, spin and parity assignments were taken from earlier work[2,6,7]. Weak transitions at 2246 kev, 880 kev and 1669 kev have also been observed but not included in that scheme. As to the first one, although it has been detected when the nominal maximum energy of the beam was bellow the threshold for $^{27}Al(\gamma,{}^3He)^{24}Na$ reaction, it fits the general aspects of the first escape peak of the 2754 kev gamma ray from that spurious activity and could not be disclosed from that. The gamma ray at 880 kev appears only in gated spectra, coincident with 1157 kev gammas; since assess of its location is difficult, owing both to its low intensity and its proximity to the Compton edge of the gating gammas which feed through the input of the MCA in random events, it might possibly be taken for the 810 kev gamma ray reported in ref. 9, 10. In that case this experiment would be inconsistent with the suggestion, by those authors, that the 810 kev gammas connect levels at 3667 and 2850 kev, since the 564 kev gammas, which are fairly intense and depopulate this last level, did not appear in those spectra (Fig. 7, 10). The 1669 kev gamma rays, which appear in singles as well as gated spectra, could not be disclosed from the random sum peak of the intense annihilation radiation and the 1157 gamma rays.

564 kev gamma rays fit quite well the transition between states at 2850 kev, $J^{\pi}=4^{+}$, $\nu=2$, as predicted by Talmi and reported in ref. 10, 18, and

at 2285 kev. Those gamma rays had been reported before in a previous run on $^{44}Ca$ at this institute[24]. In spite of its close proximity to the energy position predicted by Talmi, the interpretation of that level as $(f7/2)^4$, $J^\pi = 4^+$, $\nu=2$ is by no means simple. There are only two $J^\pi = 4^+$ levels in the $(f7/2)^4$ configuration, with $\nu=2$ and $\nu=4$, respectively, available for $^{44}Ca$[18] and experimental evidence [2, 6, 7] favours strongly the levels at 3049 kev ($\nu=2$) and 2285 kev ($\nu=4$) as the most likely candidates for those assignments. On the other hand the log ft value for the beta branching from $^{44}Sc$ found in this experiment is consistent with allowed or first forbidden decay, both of which exclude the assignment $J^\pi=4^+$ for that level, the possible $J^\pi$ values consistent with the degree of forbidness of the beta transition being $6^+$, $5^+$, $6^-$, $5^-$, $4^-$. Negative parity states are experimentally found only at energies above 3310 kev in $^{44}Ca$[7], the first one being a $3^-$ octupole vibration. Other chances for negative parity, lower in energy, might come from core excitations of the type $(f7/2)^3$ $(d3/2)^1$ (mixing with $g^{9/2}$ is not as likely even for higher deformations), but in that case $J^\pi=6^-$ is ruled out. If $J^\pi=6^+$, $5^+$, the allowed beta transition affects necessarily one f7/2 nucleon, so that the final state is either pure $(f7/2)^4$ or possibly involves mixing with $(f7/2)^3$ $(p^{3/2})^1$[25]. In the first case the assumption $J^\pi=6^+$ ($\nu=2$) is excluded by experimental evidence, which favours the level at 3287 kev[7]; if the second assumption holds true, $J^\pi$ maximum is $5^+$. Therefore one is left with the following possible spin-parity assignments for that level: $J^\pi=5^+;5^-;4^-$.

If the beta transition is an allowed one then only $j^\pi = 5^+$ is possible, but in that case, since the value obtained for log ft indicates some degree of l-forbidness(log ft =7,66), the configuration is not likely to be a pure $(f7/2)^4$, owing to the currently accepted[26] $(f7/2)^4$ character of the $6^+$ isomeric state in $^{44}Sc$. If the beta transition is first forbidden, then the most likely assignment is $J^{\pi}=5^{-}$, since the logft value obtained is right on the lower limit currently accepted to identify the $\Delta J=1$ - unique transition which would be consistent with $J^{\pi}=4^{-}$.

Therefore $J^{\pi}=5^{(+,-)}$ seems to be the assignment that fits best the results of this experiment and other available data, ruled out the expectation that the 2850 kev level in $^{44}Ca$ be the seniority analogue of the 3167 kev level in $^{52}Cr$, in both cases.

The 728 kev gamma rays found in this experiment are fed only through beta decay from the ground state of $^{44}Sc$ to the $0^{+}$ - 1885 kev level in $^{44}Ca$. The estimated log ft is 8.6, which is consistent with $\Delta J=2$, no parity change; the transition is then j-forbidden if the level in $^{44}Ca$ is pure $(f7/2)^{4}$. This result is consistent with current views about the structure of the level[14, 23], which consists of core excited configurations of the type $(f7/2)^{6}$ $(d3/2)^{-2}$, $(f7/2 - p3/2)^{6}$ $(s1/2 - d3/2)^{-2}$.

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* * *

TABLE I

| INITIAL STATE | | FINAL STATE | | γ - RAY TRANSITION | | |
|---|---|---|---|---|---|---|
| $J_i^{\pi}$ | ENERGY kev | $J_i^{\pi}$ | ENERGY kev | ENERGY kev | TYPE | RELATIVE INTENSITY % |
| $(5^+, 6^+)$ | 3667 | $5^{(\pm)}$ | 2850 | (880) | (E2) | 0.1 |
| $2^+$ | 3303 | $2^+$ | 1157 | (2246) | (M1) | 0.15 |
| $6^+$ | 3287 | $4^+$ | 2285 | 1002 | E2 | 1.2 |
| $(5)^{\pm}$ | 2850 | $2^+$ | 1157 | (1689) | (E2) | 0.25 |
| $(5)^{\pm}$ | 2850 | $4^+$ | 2285 | 564 | (E2) | 2. |
| $2^+$ | 2657 | $0^+$ | 0 | 2657 | E2 | 0.13 |
| $2^+$ | 2657 | $2^+$ | 1157 | 1500 | M1+E2 | 0.76 |
| $4^+$ | 2285 | $2^+$ | 1157 | 1127 | E2 | 1.3 |
| $0^+$ | 1885 | $2^+$ | 1157 | 728 | E2 | 0.1 |
| $2^+$ | 1157 | $0^+$ | 0 | 1157 | E2 | 100. |

COINCIDENCE BLOCK DIAGRAM

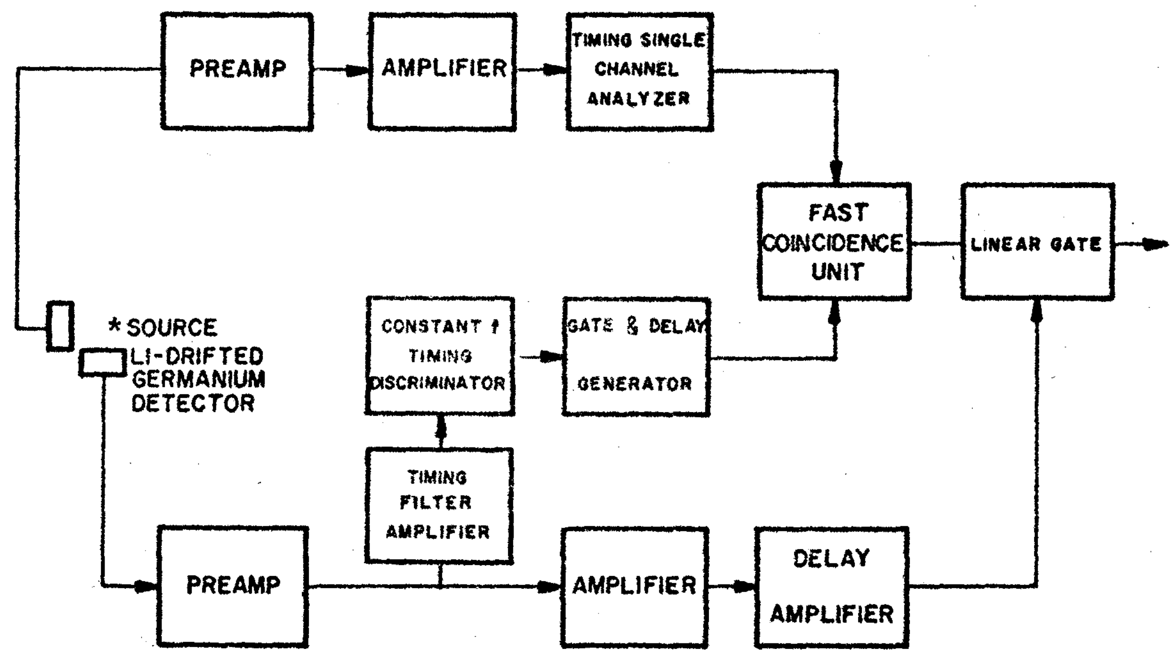


Figure 1

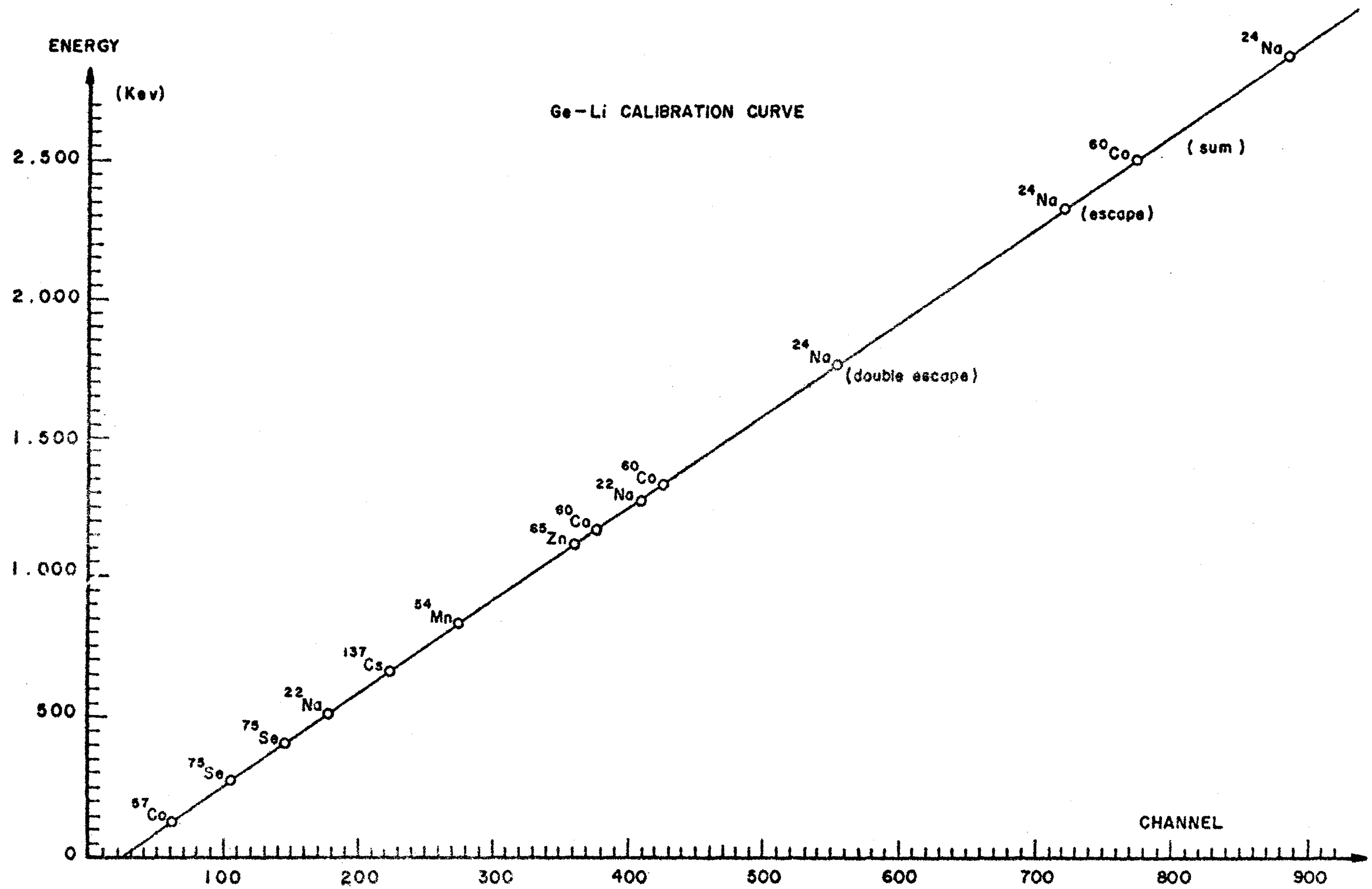
ENERGY
(Kev)
Ge-Li CALIBRATION CURVE
2,500
2,000
1,500
1,000
500
0
100
200
300
400
500
600
700
800
900
CHANNEL
57Co
75Se
75Se
22Na
137Cs
54Mn
65Zn
60Co
22Na
60Co
24Na
(double escape)
24Na
(escape)
60Co
(sum)
24Na

Figure 2

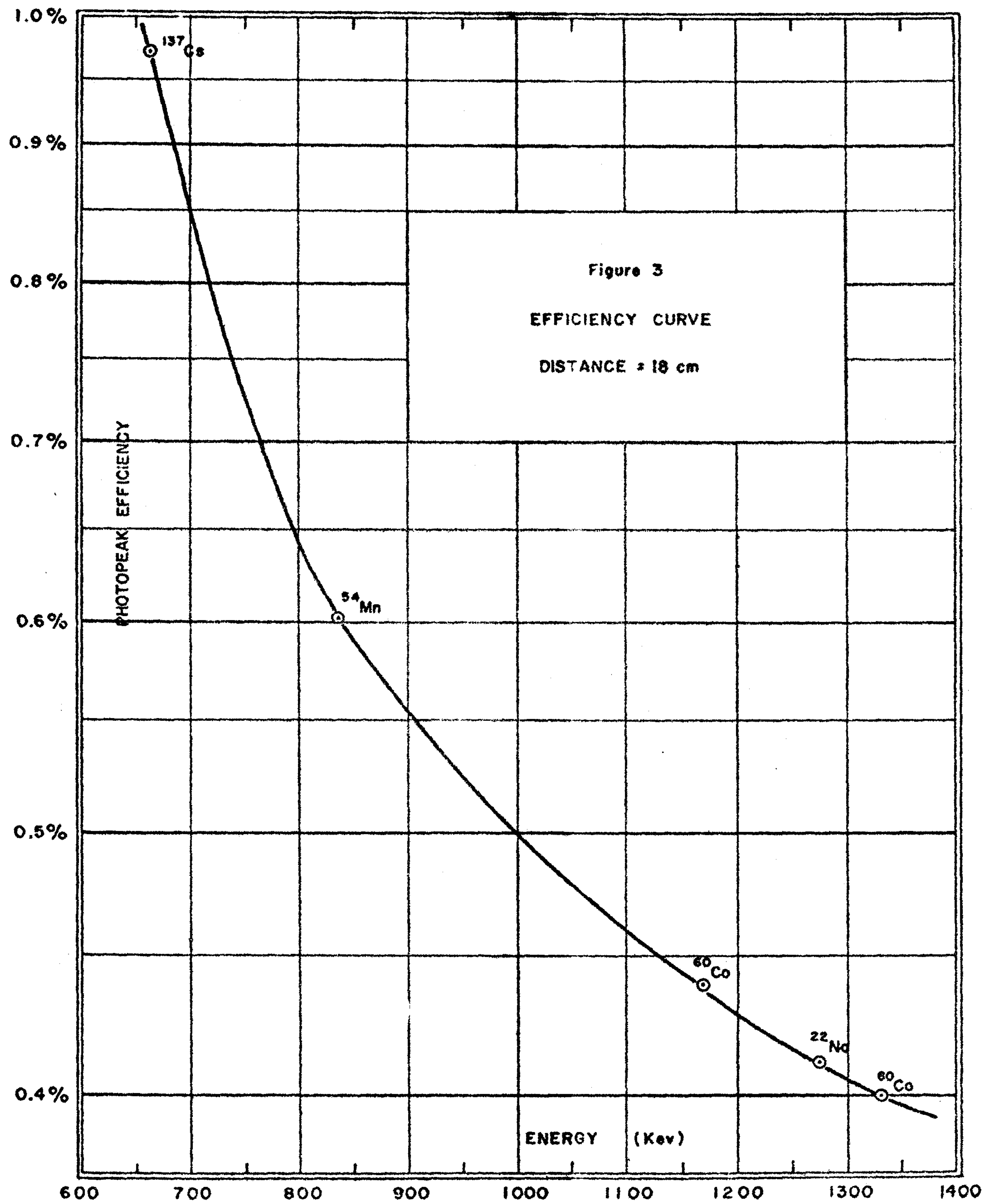

Figure 3
EFFICIENCY CURVE
DISTANCE = 18 cm
PHOTOPEAK EFFICIENCY
ENERGY (Kev)
1.0%
0.9%
0.8%
0.7%
0.6%
0.5%
0.4%
600
700
800
900
1000
1100
1200
1300
1400
137Cs
54Mn
60Co
22Na
60Co

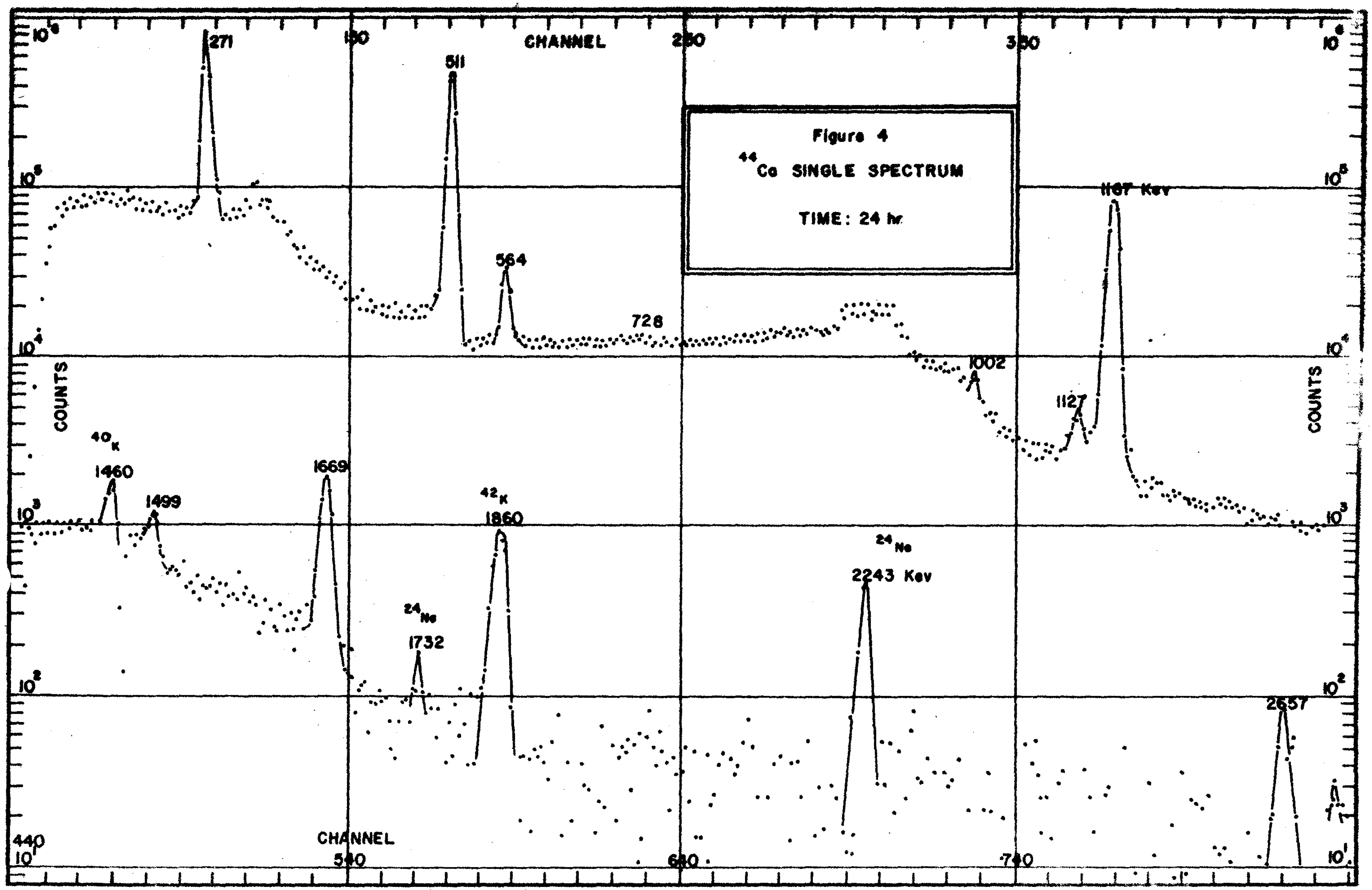

Figure 4
$^{44}$Ca SINGLE SPECTRUM
TIME: 24 hr.
CHANNEL
CHANNEL
COUNTS
COUNTS
150
250
350
440
540
640
740
271
511
564
728
1002
1127
1167 Kev
$^{40}$K
1460
1499
1669
$^{42}$K
1860
$^{24}$Na
1732
$^{24}$Na
2243 Kev
2657

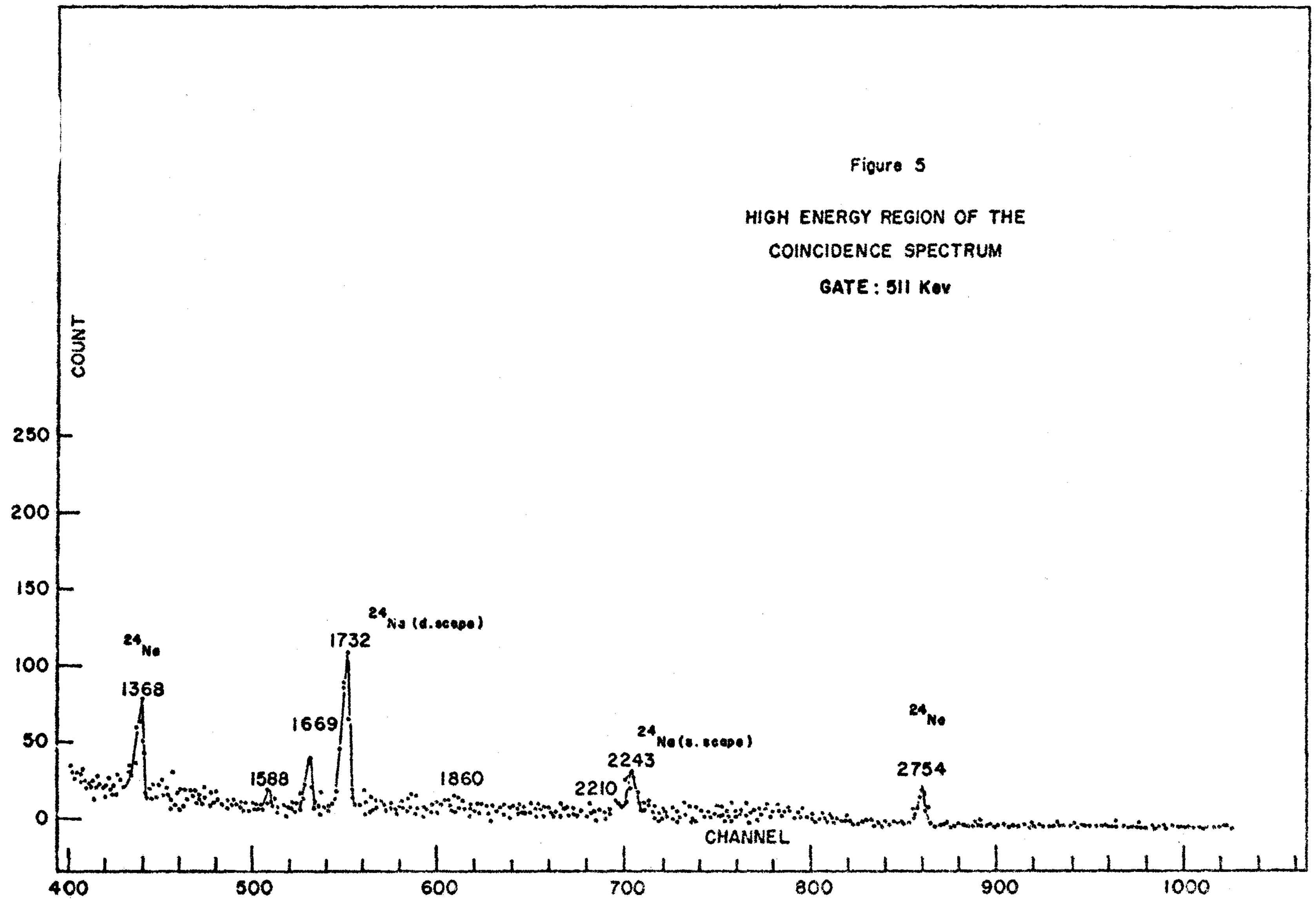


Figure 5

HIGH ENERGY REGION OF THE COINCIDENCE SPECTRUM

GATE: 511 Kev

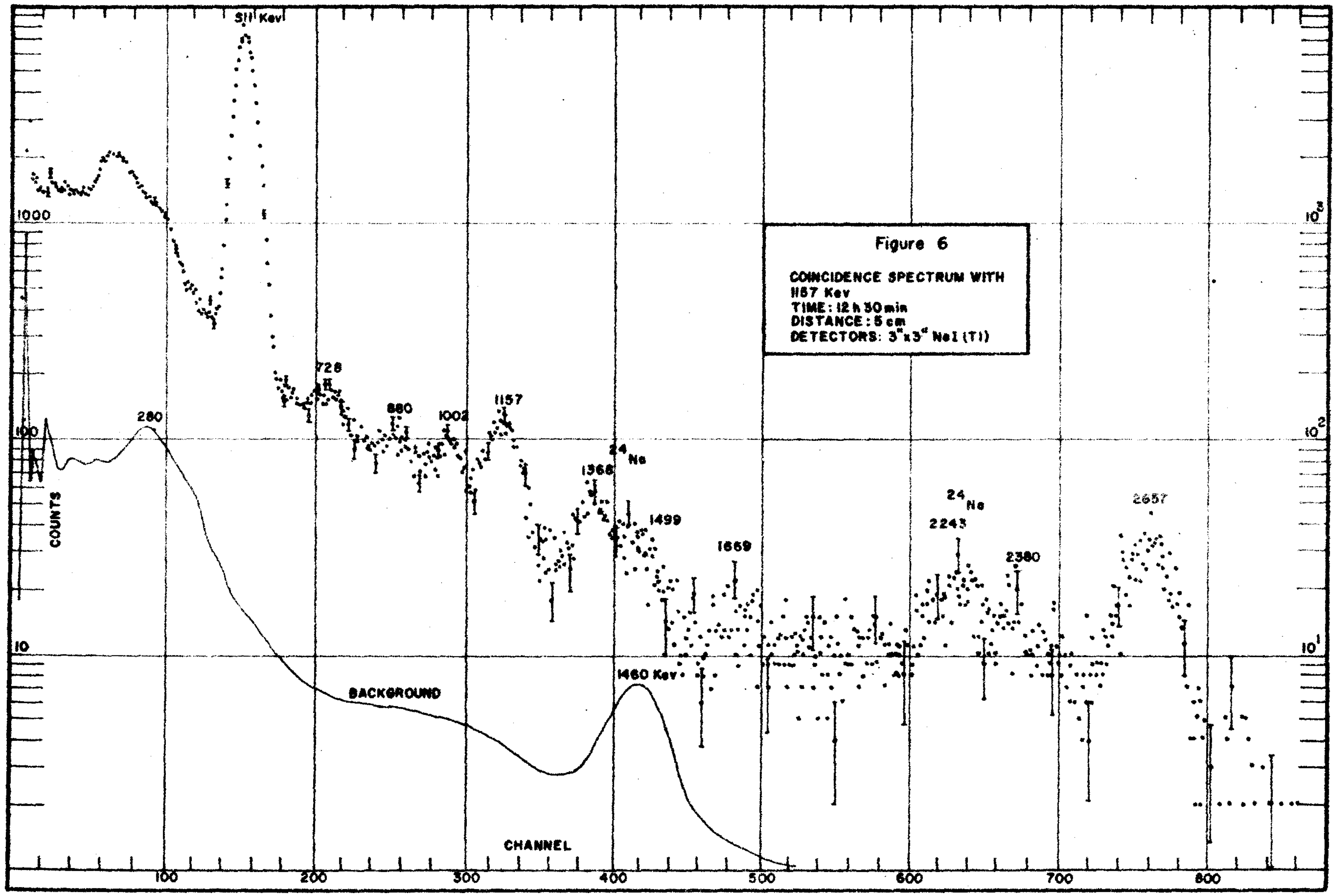

Figure 6
COINCIDENCE SPECTRUM WITH
1157 Kev
TIME: 12 h 30 min
DISTANCE: 5 cm
DETECTORS: 3"x3" NaI (Tl)
511 Kev
728
880
1002
1157
1368
24 Na
1499
1669
24 Na
2243
2380
2657
280
BACKGROUND
1460 Kev
COUNTS
CHANNEL
1000
100
10
$10^3$
$10^2$
$10^1$
100
200
300
400
500
600
700
800

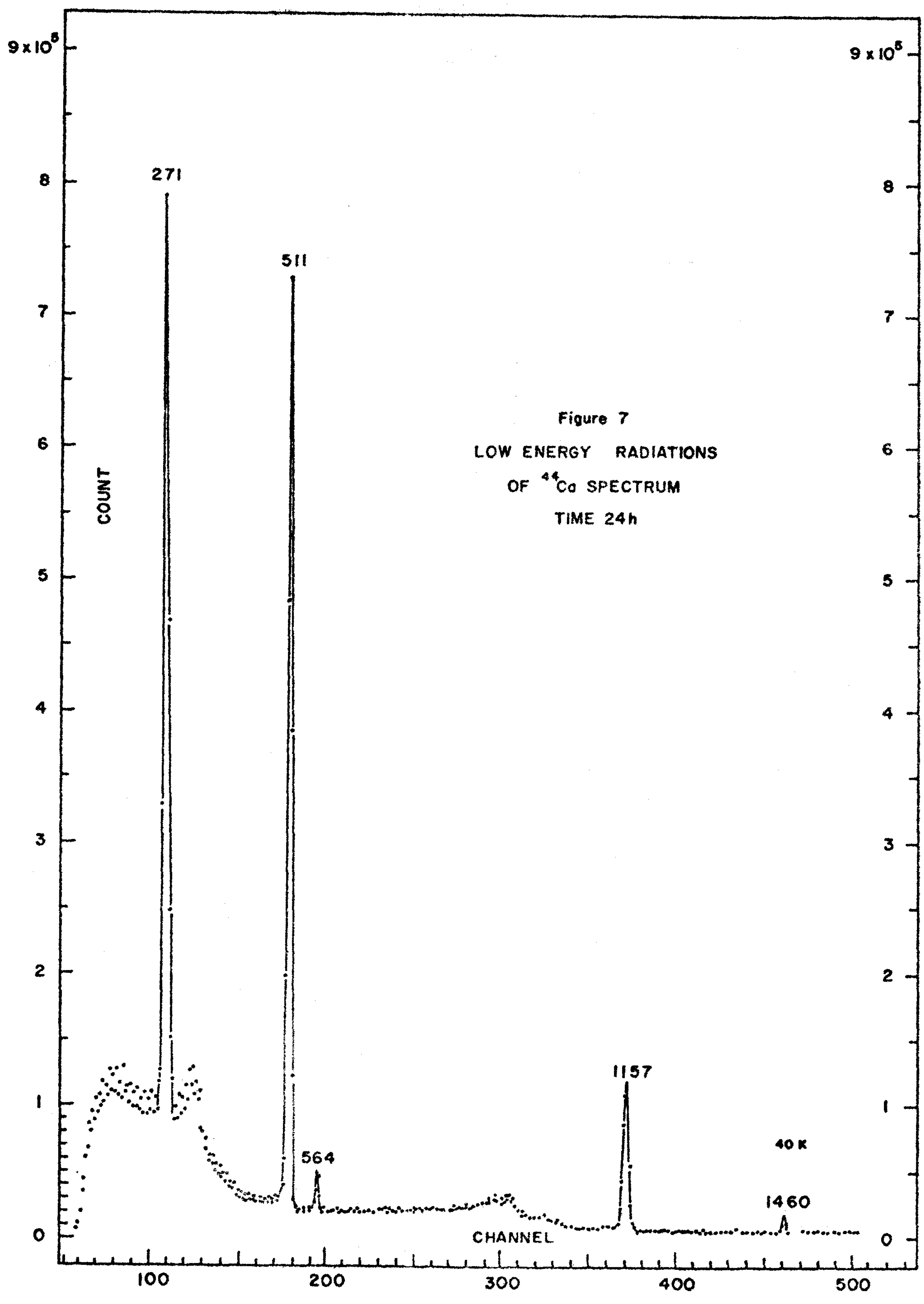

Figure 7
LOW ENERGY RADIATIONS
OF 44Ca SPECTRUM
TIME 24h
COUNT
CHANNEL
9 x 10^5
8
7
6
5
4
3
2
1
0
100
200
300
400
500
271
511
564
1157
40 K
1460

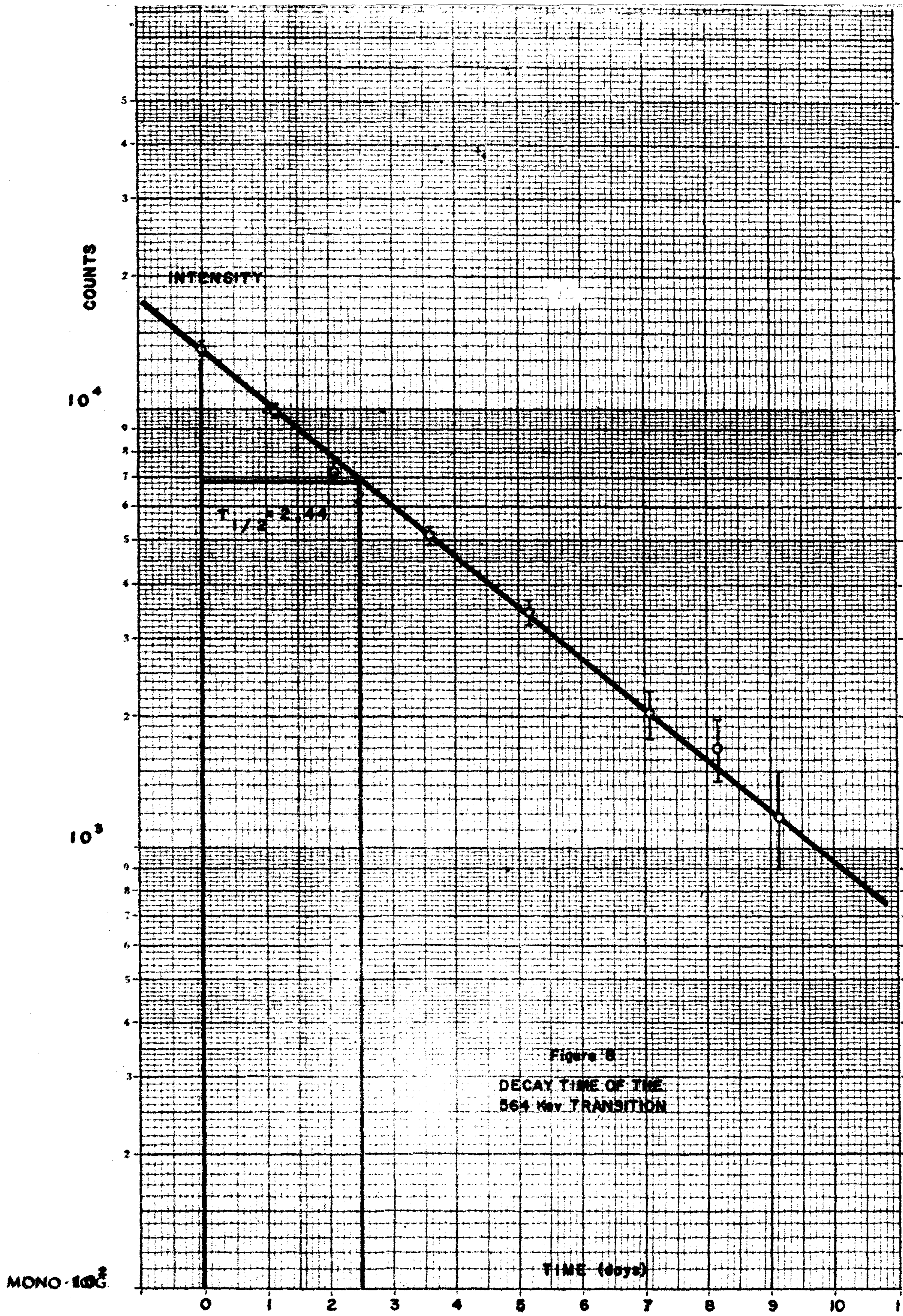

Figure 8
DECAY TIME OF THE 564 Kev TRANSITION

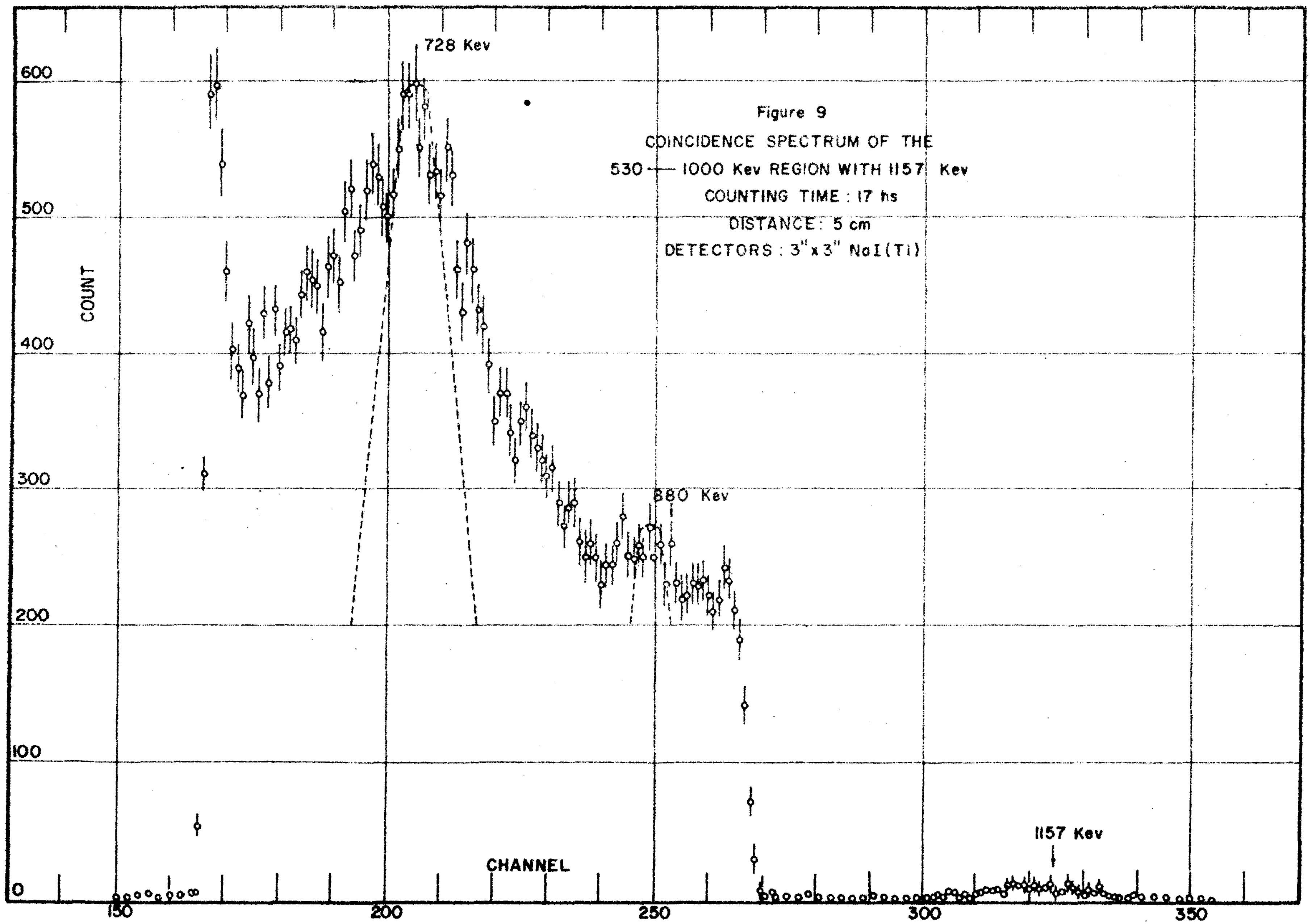

Figure 9
COINCIDENCE SPECTRUM OF THE
530 — 1000 Kev REGION WITH 1157 Kev
COUNTING TIME : 17 hs
DISTANCE : 5 cm
DETECTORS : 3"x3" NaI(Ti)
728 Kev
880 Kev
1157 Kev
COUNT
CHANNEL
0
100
200
300
400
500
600
150
200
250
300
350

## DECAY SCHEME*

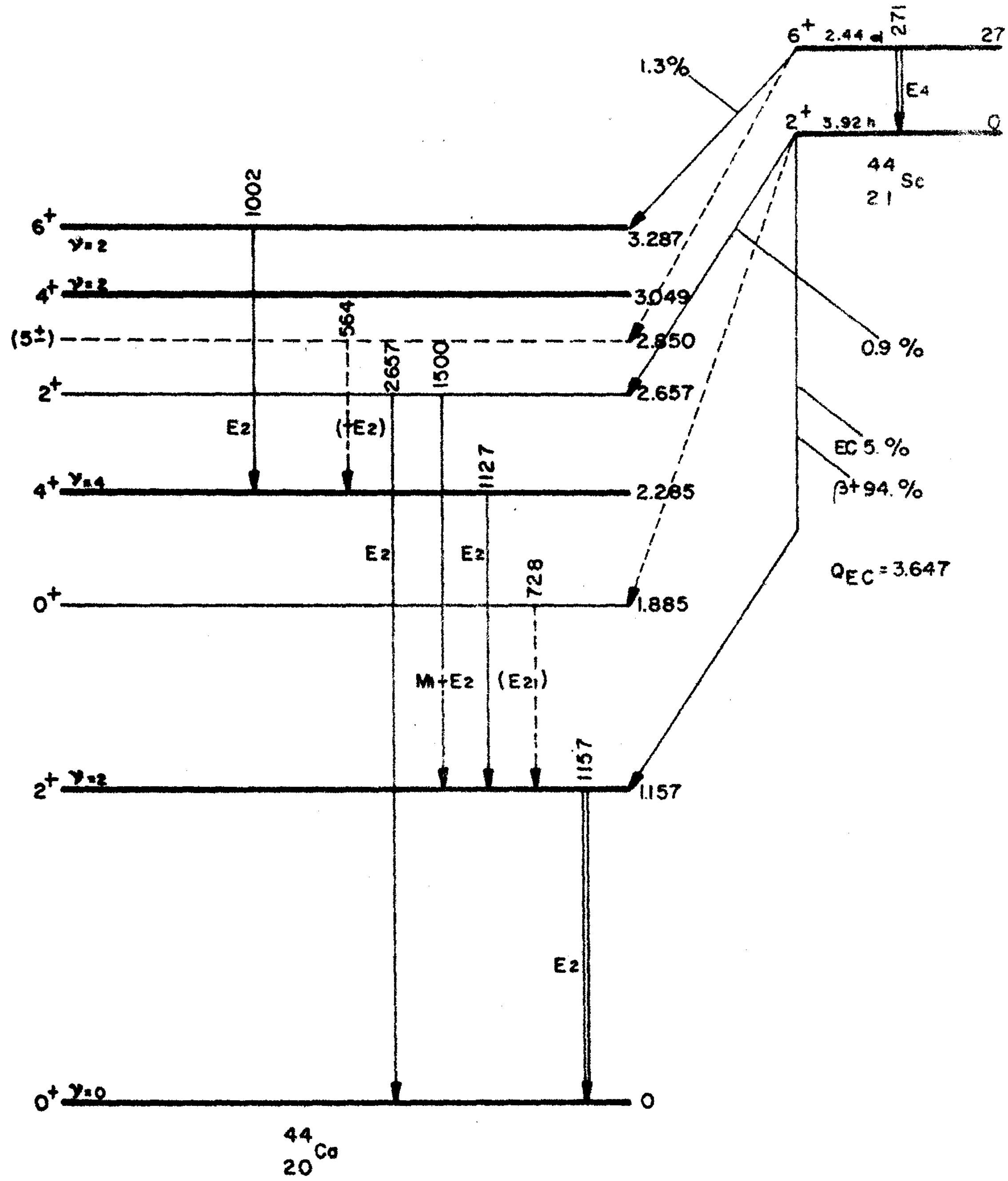


Figure 10

* Beta Branching Ratios From Table
Of Isotopes: Lederer, Hollander, Perlman — J.W. 1967