INFN/TC-91/02
21 Marzo 1991

NEUTRON BACKGROUND DETERMINATION IN THE GRAN SASSO LABORATORY BY MEANS OF A NOVEL COINCIDENCE NEUTRON SPECTROMETER

S. Affatato, A. Bertin, M. Bruschi, D. Bulgarelli, V.M. Bystritsky, M. Capponi, I. D'Antone, S. De Castro, D. Galli, U. Marconi, I. Massa, M. Morganti, C. Moroni, M. Piccinini, M. Poli, N. Semprini-Cesari, M. Villa, A. Vitale, G. Zavattini, A. Zoccoli

INFN - Laboratori Nazionali del Gran Sasso

INFN/TC-91/02
21 Marzo 1991

NEUTRON BACKGROUND DETERMINATION IN THE GRAN SASSO LABORATORY BY MEANS OF A NOVEL COINCIDENCE NEUTRON SPECTROMETER

S. Affatato, A. Bertin, M. Bruschi, D. Bulgarelli, V.M. Bystritsky, M. Capponi, I. D'Antone, S. De Castro, D. Galli, U. Marconi, I. Massa, M. Morganti, C. Moroni, M. Piccinini, M. Poli, N. Semprini-Cesari, M. Villa, A. Vitale, G. Zavattini, A. Zoccoli

INFN - Laboratori Nazionali del Gran Sasso

INFN - Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

INFN/TC-91/02
21 Marzo 1991

NEUTRON BACKGROUND DETERMINATION IN THE GRAN SASSO LABORATORY BY MEANS OF A NOVEL COINCIDENCE NEUTRON SPECTROMETER

S. Affatato, A. Bertin, M. Bruschi, D. Bulgarelli, V. M. Bystritsky(*), M. Capponi, I. D'Antone, S. De Castro, D. Galli, U. Marconi, I. Massa, M. Morganti, C. Moroni, M. Piccinini, M. Poli(**), N. Semprini-Cesari, M. Villa, A. Vitale, G. Zavattini and A. Zoccoli

Dipartimento di Fisica dell'Università di Bologna, and Istituto Nazionale di Fisica Nucleare, Sezione di Bologna, Italy

(*) *On leave of absence from JINR, Dubna, USSR*

(**) *Dipartimento di Energetica dell'Università di Firenze, and Istituto Nazionale di Fisica Nucleare, Sezione di Bologna, Italy*

ABSTRACT

We present the results of recent background measurements in the Gran Sasso Laboratory. The measurements were performed by a coincidence neutron spectrometer, allowing neutron identification by means of two different stages of pulse-amplitude analysis.

Printed and Published by
Servizio Documentazione
dei Laboratori Nazionali di Frascati

1. - INTRODUCTION

We have built a coincidence neutron spectrometer, aiming to the detection of low-level neutron emissions within a significant gamma-ray background.

The spectrometer[1,2] is constituted by an aluminium cubic cell ($10\text{x}10\text{x}10$ cm^3 in volume) seen at two opposite faces by EMI 9823 phototubes, 5" in diameter, the signals of which are summed to get the relevant amplitude information.

The cell is filled with NE 213 C liquid scintillator. Within the cell, three 1.5 mm thick ^{6}Li glasses are placed, 2.5 cm apart from each other, their planes being parallel to the phototube surfaces.

The cell dimensions were optimized for the purpose of total energy absorption of neutrons in the MeV range. Once thermalized, the neutrons attaining one ^{6}Li glass undergo the capture reaction $n + {}^6Li \rightarrow t + He + 4.8$ MeV.

A neutron candidate event is defined3) by the coincidence of a prompt scintillation signal (nominally due to the total energy loss of the neutron within the NE 213 C liquid) with a delayed one (within a time gate $\Delta T = 10\text{-}20\ \mu s$), as expected from the capture reaction in the ^{6}Li glasses.

For such an event, five amplitudes are recorded:

a) E and T amplitudes for the prompt signals - Following the established technique4) of gating separately the fast (E) and slow (T) components of the liquid scintillation pulse, one gets in this way:

i) the energy of the detected neutron from the E-amplitude. In time-of-flight measurements with an Am-Be source, well defined amplitude peaks were obtained for neutrons in the MeV range.1,2)

ii) a two-dimensional (E,T) plot for the events recorded, in which neutrons and accidentally recorded gamma-rays distribute themselves in two (scissors-like) different regions, allowing thereby an effective neutron-gamma pulse-shape discrimination (PSD).

b) E and T amplitudes, and total voltage amplitude, of the delayed pulses - Requiring that the charge signal of the delayed pulses is shared in similar proportions between the relevant E and T gates, (which work independently of those operating on the prompt signals) neutron signals cluster in a well identified zone of the corresponding (E,T) plot. The voltage amplitude distribution, in its turn, is characteristically peaked, as expected from a scintillation signal due to the two-body capture reaction of thermalized neutrons within the ^{6}Li glasses.

The off-line analysis of these information allows for the first time to perform a double-checked PSD on the recorded neutron-candidate events. This proved to be essential (while operating the present spectrometer) to reject both accidental and other types of backgrounds which might interfere with the detection of a low-level neutron emission.

In what follows, we present an example of the spectrometer performances, by discussing the results obtained in recent background measurements carried out in the Gran Sasso Laboratory Hall C.

2. - *MEASUREMENTS*

Pulse-shape discrimination - The performances of the apparatus under this respect were checked by the Am-Be source. In single-counting (see Fig.l), the source was providing a counting rate of about 100 s^{-1}. The neutron/gamma ratio, established by PSD on the (E,T) plot of Fig. 1, was about 2.5. It is seen in Fig. 1 a) that, aside of the two familiar neutron and gamma (upper and lower) scissors-like bands, one third branch is present, pointing upwards from the low-energy region of the neutron band. In this single-counting display, where the prompt and delayed signals previously defined are mixed, this third branch is mainly due to thermal neutrons producing delayed scintillation light within the ^{6}Li glasses.$^{1)}$

The results obtained for the same measurement, through the coincidence operation of the spectrometer, are shown in Figs. 2 and 3.

In Fig.2, where the prompt pulses amplitudes are displayed, it is seen that the coincidence request increases the ratio of detected neutrons/gammas to about 14. (The detection efficiency for neutrons (from the Am-Be source) is decreased by a factor of about 6×10^{-2} by the coincidence requirement). The residual gamma-ray counting rate is compatible with the expected rate of accidental coincidences, given the single counting rate of the spectrometer and the chosen duration of the gate ~T. This fact emphasizes the importance of PSD to remove the accidentally recorded gammas, especially for the case in which a low-level neutron emission is to be detected.

In Fig.3 the amplitudes of the delayed signals are displayed, showing as advanced that the neutron signals (which are dominant after the coincidence request) gather in a fairly well defined region of the (E,T) plot (Fig.3a)), and have a well peaked total voltage amplitude distribution (Fig.3b)). Setting on these amplitudes conservative cuts (100-190, abscissae, and 100-165, ordinates, for Fig.3a); 300-550, for Fig.3b)) decreases the neutron acceptance for about 30%, and increases the neutron/gamma ratio to about 19.

Background measurements - Long duration background measurements were started at the Gran Sasso Laboratory, where an additional 4π screen of low-activity lead bricks$^{5)}$ was constructed around the spectrometer. The lead shield reduced the natural gamma-ray background for a factor larger than 6.

The results obtained during a typical (15 hours) background run are summarized in Table I. The corresponding display of the prompt and delayed amplitudes of the events recorded by the spectrometer working in the coincidence setting is shown in Figs.4 and 5, respectively.

From Fig.4, the presence of background prompt signals contaminating the neutron region is apparent. On the other hand, the amplitude display of the corresponding delayed pulses (Fig.5) show that the background signals distribute themselves in regions well distinguished from those where physical neutrons signals are located (see for comparison Fig.3).

The nature of these background counts, which show up only in long duration measurements, and in the absence of a significant physical neutron or gamma-radiation level has not been cleared up so far. In any case, the comparison of Figs.3 and 5 leads to exclude that these spurions background counts are due to neutrons.

If in the background measurement to which Table I refers we introduce on the amplitudes of the delayed signals the cuts suggested from Fig.3, one gets for the prompt signals amplitude display the results shown in Fig.6. Out of more than 1.5×10^5 events detected in the single-counting operation (see Table I), only two survive the (coincidence + delayed pulse analysis) selection; on the basis of the reference (E,T) plot of the prompt amplitudes (see Fig. 1), only one of these last remains as a neutron candidate.

3. - *CONCLUSIONS*

The results obtained in subsequent background runs were coherent with those discussed in the previous Section, showing stability of the spectrometer performances and of periodical calibrations performed by Am-Be, ^{22}Na and ^{137}Cs radioactive sources.

We should therefore draw the following conclusions:

i) The coincidence operation of the spectrometer reduces the gamma-background counting rate (PSD - selected, with a lower energy cut at 0.34 MeV - electron equivalent energy) by a factor of about 750. [See Table I]

ii) The extended background measurements yielded an average rate for the neutron-candidate signals (identified through (a) the coincidence operation; (b) PSD on the prompt pulses; (c) the described cuts on the delayed pulses amplitudes) close to $6 \times 10^{-6}\ s^{-1}$. Keeping into account the absolute neutron counting efficiency of the present spectrometer (which we evaluate around a few percent) and the detector surface, this counting rate is compatible with the results obtained for the neutron background under the Gran Sasso tunnel by other authors.6)

iii) The efficiency of the spectrometer for detecting 2.5 MeV neutrons is decreased by a factor of about 20 by the coincidence operation.1)

Assuming to deal with a reference single-counting rate of $10^{-2}\ s^{-1}$ 2.5 MeV neutrons, one would then expect a coincidence counting rate of $5 \times 10^{-4}\ n.s^{-1}$ in the present apparatus. This would correspond to a signal-to-noise ratio $R \cong 80$ in the present conditions, to be compared to $R \cong 0.2$ which was experienced in the past[7,8] in the observation of a low-level neutron emission at the quoted reference counting rate.

This comparison describes the improved possibilities of the present apparatus to be used for similar purposes in the Gran Sasso Laboratory.

Acknowledgements - The authors are indebted to E.Bellotti, Director of the Gran Sasso Laboratory, and to the Laboratory staff for hospitality and friendly collaboration. They should like to acknowledge the collaboration of T.Wilson and K.Parnham, of NE Technology Ltd, Sighthill, Edinburgh, while assembling the spectrometer. They are indebted to E.Zavattini, S.E.Jones and J.B.Czirr for useful discussions.

Table I - Background counts per second in the Gran Sasso Laboratory (Hall C) recorded during a typical 15 hours run by the present spectrometer.[a)]

Working condition	Gamma-rays[b)]	Neutron Candidates[b)]
Single counting	~ 3	~ 0.1
Coincidence counting	$\sim 4 \times 10^{-3}$	$\sim 1 \times 10^{-3}$
Coincidence counting plus amplitude analysis of the delayed pulses	$\sim 2 \times 10^{-5}$	$\sim 2 \times 10^{-5}$

[a)] Lower energy cut: 0.3 MeV (electron equivalent energies); [b)] As identified through off-line PSD of the prompt pulses (on the basis of calibration plots like the one of Fig. 1).

REFERENCES

1. A.Bertin, M.Bruschi, D.Bulgarelli, M.Capponi, I.D'Antone, S.De Castro, D.Galli, U.Marconi, M.Morganti, C.Moroni, M.Piccinini, M.Poli, N.Semprini-Cesari, M.Villa, A.Vitale, G.Zavattini, and A.Zoccoli, A Novel Neutron Spectrometer with Neutron-Gamma Pulse-Shape Discrimination, to be published on Muon Catalyzed Fusion.

2. S.Affatato, A.Bertin, M.Bruschi, D.Bulgarelli, V.M.Bystritsky, M.Capponi, I.D'Antone, S.De Castro, D.Galli, I.Massa, U.Marconi, M.Morganti, C.Moroni, M.Piccinini, M.Poli, N.Semprini-Cesari, M.Villa, A.Vitale, G.Zavattini and A.Zoccoli, Measurement of a Very Low Neutron Background within a Significant Gamma-Ray Environment by Means of a Coincidence Spectrometer with n-γ Pulse-Shape Discrimination, Proc. of Int. Progr. Rev. on Anomalous Nuclear Effects in Deuteriurn/Solid Systems, BYU, October 22-23, 1990 (to be published on AIP Conference Serios).

3. S.E.Jones, E.P.Palmer, J.B.Czirr, D.L.Decker, G.L.Jensen, J.M.Thorne, S.F.Taylor and J.Rafelski, Nature 338,737(1989); J.B.Czirr, and G.L.Jensen, Nucl. Instr. and Meth. A 284, 365(1989).

4. See e.g. A.Bertin, A.Vitale and A.Placci, Nucl. Instr. and Meth. 68,24(1969); and references therein.

5. Purchased from ATEA, 44472 Carquefou Cedex, France.

6. E.Fiorini, C.Liquori, and A.Rindi, Prelirninary Measurements of the Gamma Ray and Neutron Background in the Gran Sasso Tunnel, LNF-85/7(R); R.Aleksan, J.Bouchez, M.Cribier, E.Kajfasz, B.Pichard, F.Pierre, J.Poinsignon, M.Spiro, and J.F.Thomas, Nucl. Instr. Meth. A 274,203(1989); P.Belli, R.Bernabei, S.D'Angelo, M.P.De Pascale, L.Paoluzi, R.Santonico, N.Taborgna, N.Iucci and G.Villoresi, Il Nuovo Cimento 101 A, 959(1989).

7. A.Bertin, M.Bruschi, M.Capponi, S.De Castro, U.Marconi, C.Moroni, M.Piccinini, N.Semprini-Cesari, A.Trombini, A.Vitale, A.Zoccoli, S.E.Jones, J.B.Czirr, G.L.Jensen and E.P.Palmer, Il Nuovo Cimento 101 A, 997(1989).

8. A.Bertin, M.Bruschi, M.Capponi, S.De Castro, U.Marconi, C.Moroni, M.Piccinini, N.Semprini-Cesari, A.Trombini, A.Vitale, A.Zoccoli, S.E.Jones, J.B.Czirr, G.L.Jensen and E.P.Palmer, J.Fusion Energy 2. 209(1990); A.Bertin, M.Bruschi, M.Capponi, S.De Castro, U.Marconi, C.Moroni, M.Piccinini, N.Semprini-Cesari, A.Trombini, A.Vitale, A.Zoccoli, S.E.Jones, J.B.Czirr, G.L.Jensen and E.P.Palmer, Proc. Int. Symp. on Muon Cat. Fusion μCF-89, RAL-90-022, 114(1990).

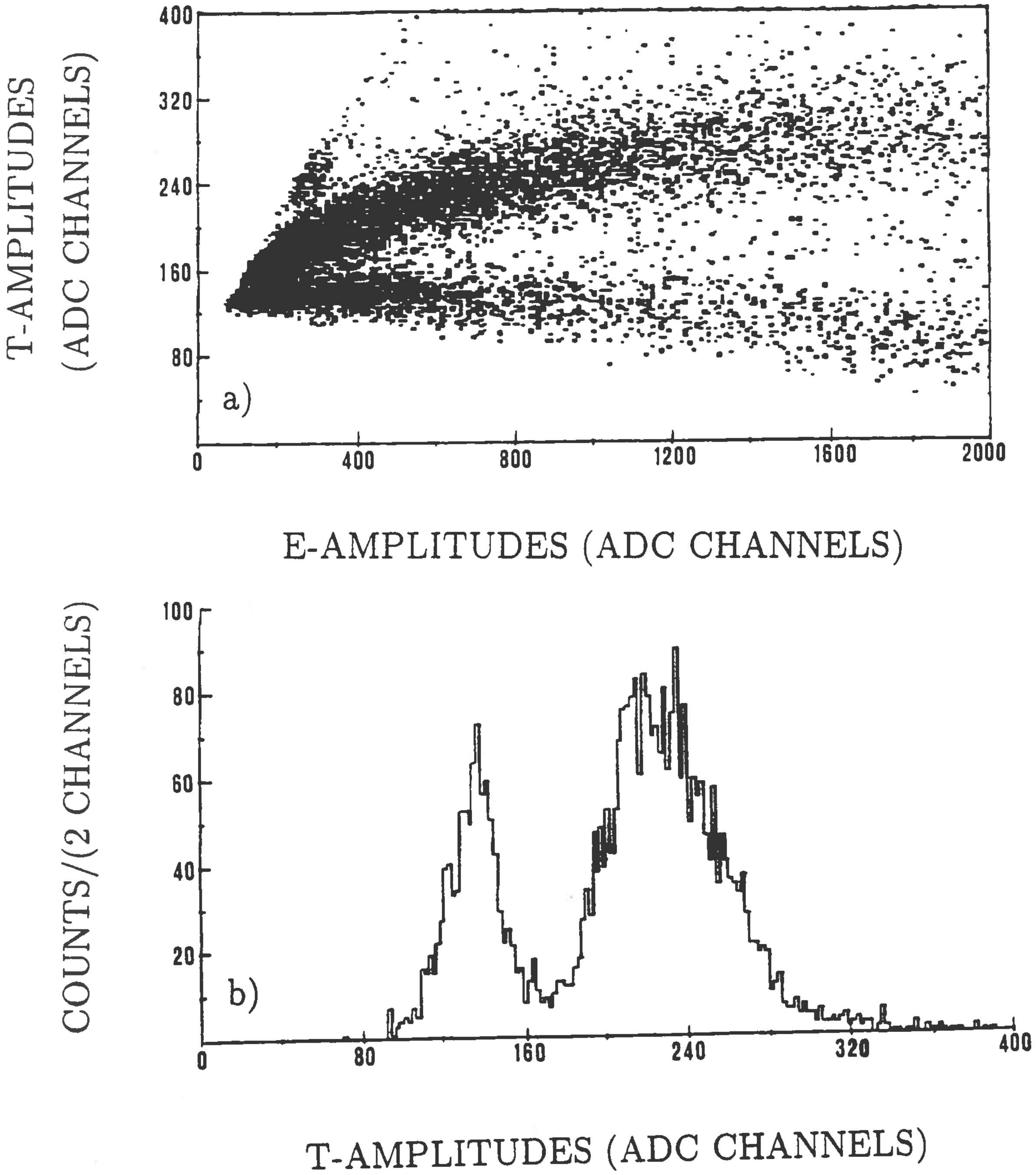

Fig. 1 - Single counting operation. *(a)* (E,T) plot of the prompt signals released by the present spectrometer viewing an Am-Be source. *Energy scale:* (1.03xabscissae-34) keV (electron equivalent energy). Total number of events: 8558. *Counting rate:* ~ 100 s^{-1}. *Scissors:* lowest band, gamma ray, and upper band, neutron prompt signals from the liquid scintillator. *Third branch:* events due to scintillation pulses within the ^{6}Li glasses. (**b**) T-amplitude distribution (obtained by projecting the events of Fig. 1 a) on the vertical axis). Number of events obtained for E-amplitudes contained between channels 364 and 1060: 3657. The ratio of neutrons (right peak, for a T-amplitude window between channels 180 and 400) to gammas (left peak) is close to 2.5.

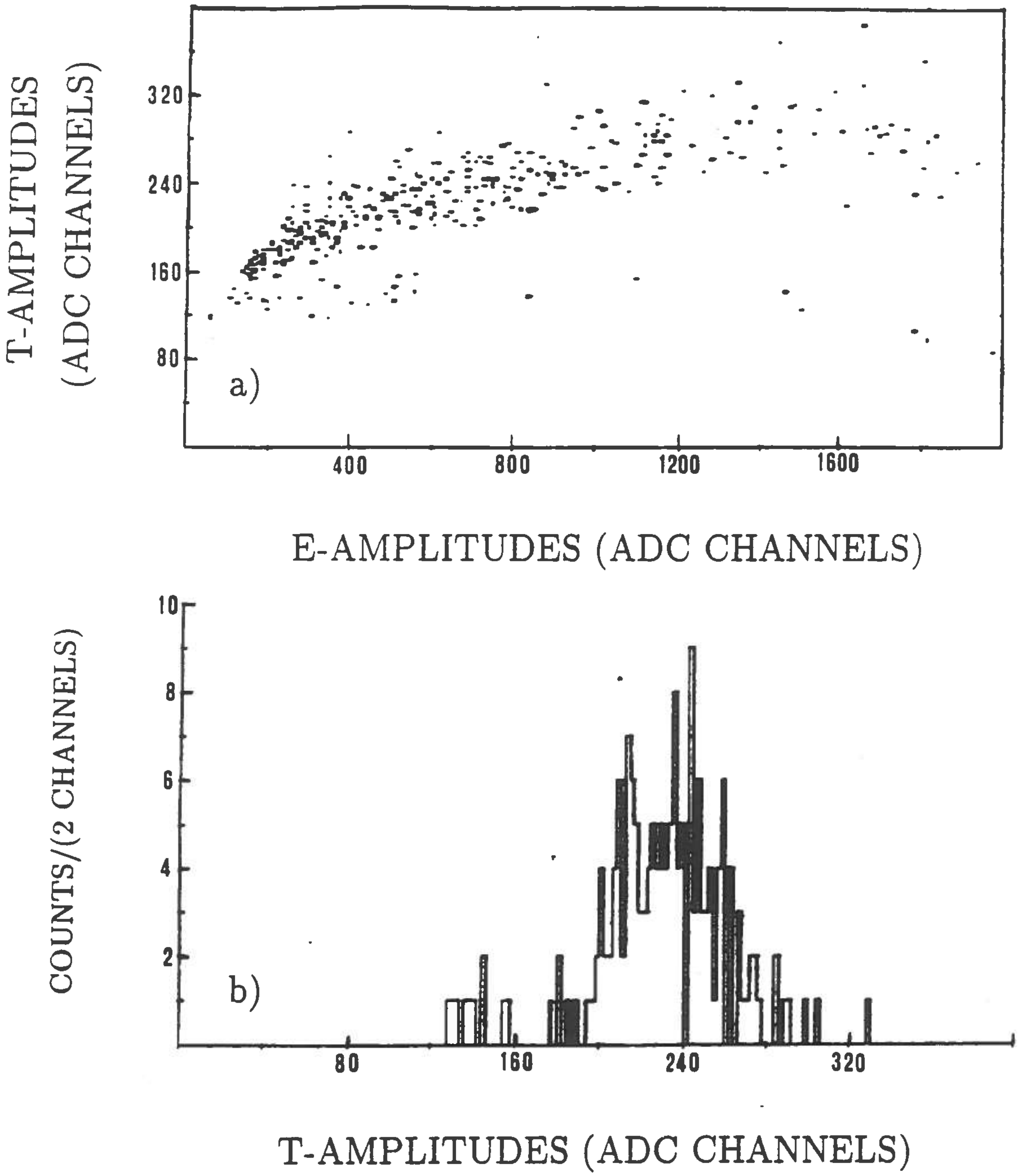

Fig. 2 - Coincidence counting operation. *(a)* (E,T) plot of the prompt signals released from the spectrometer viewing the Am-Be source in the same measurement of Fig. 1. Total number of events: 347. *Scissors:* lowest band, gamma-ray, and upper band, neutron prompt signals from the liquid scintillator. (**b**) T-amplitude distribution for the events of Fig. 2a). Number of events obtained for E-amplitudes contained between channels 364 and 1060: 167. The ratio of neutrons (right peak, for a T-amplitude window between channels 180 and 400) to gammas (left peak) is 14.2.

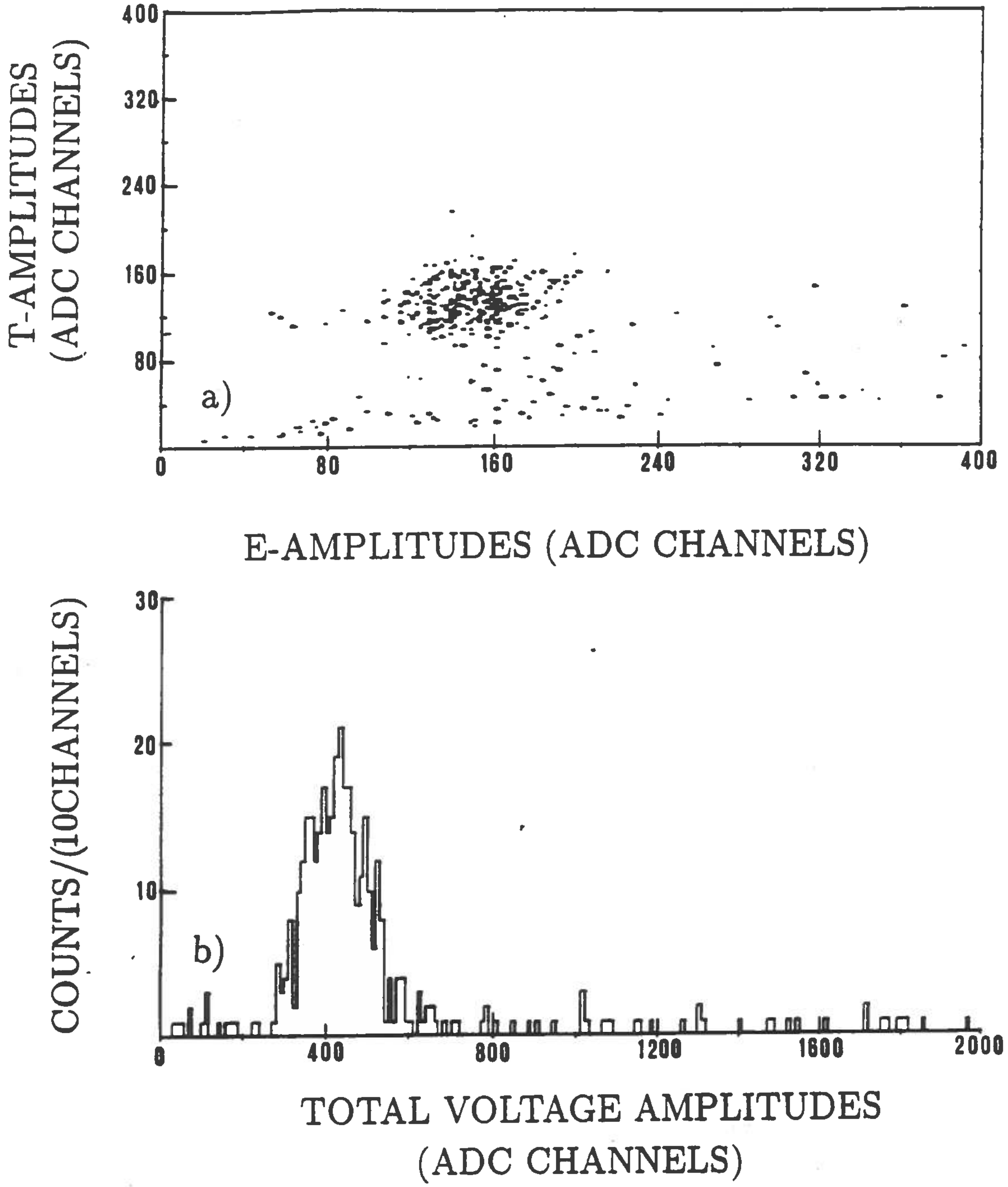

Fig. 3 - Delayed pulses amplitude analysis. *(a)* (E,T) plot of the delayed signals released from the spectrometer viewing the Am-Be source for the same measurement of Fig. 1. Total number of events: 371. The cluster of points in the middle of the Figure is due to neutrons (see for comparison Fig. 2a)). (**b**) Total amplitude (voltage) distribution of the delayed signals displayed in Fig. 3a).

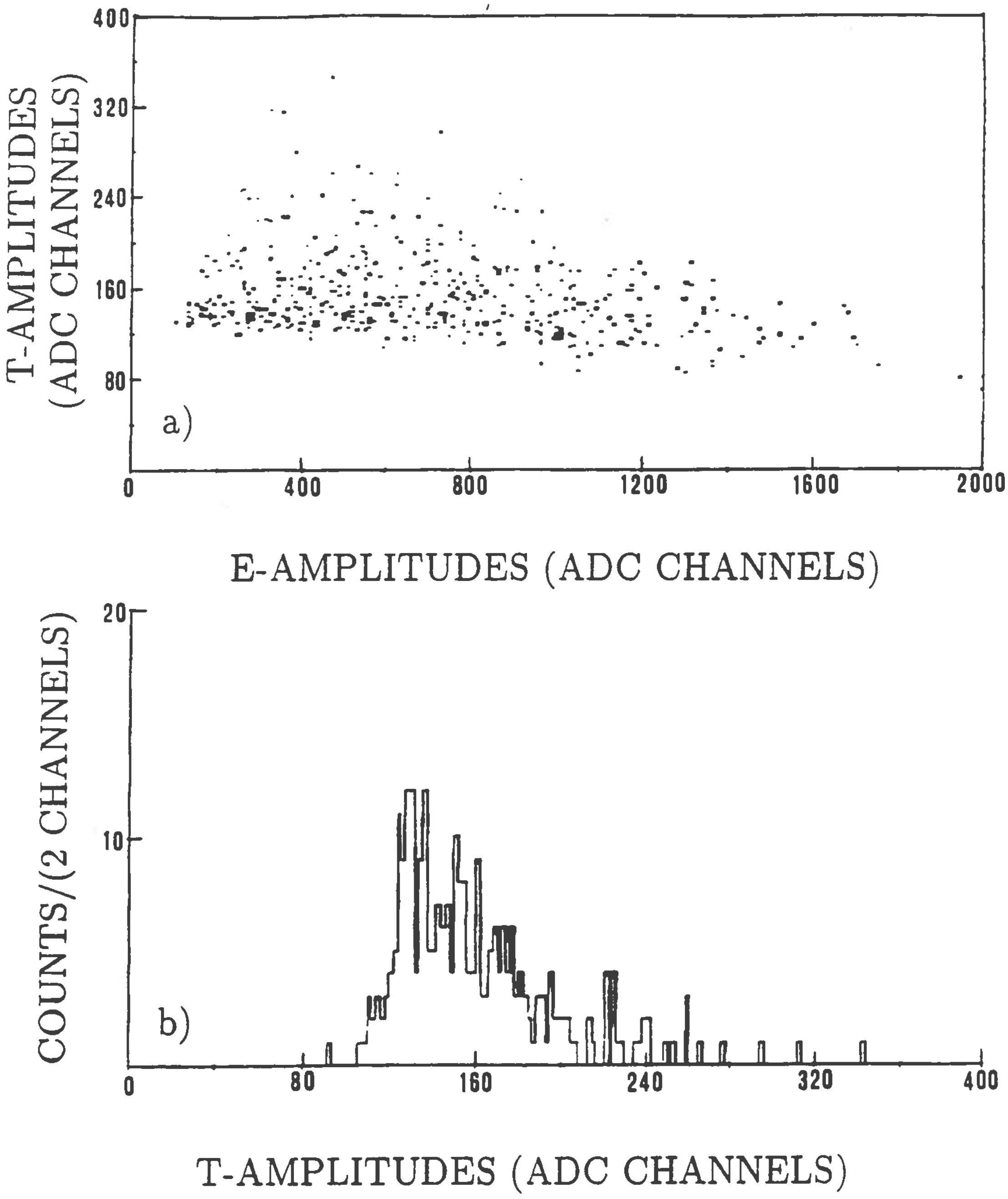

Fig. 4 - Results of the coincidence counting operation for the background measurement to which Table I refers. *(a)* (E,T) plot of the recorded prompt signals. *Energy scale:* (1.1 x abscissae-26) keV (electron equivalent energy). Total number of events: 462. (**b**) T-amplitude distribution for the events of Fig. 4a). Number of events for E-amplitudes contained within channels 333 and 989: 271. Number of events simulating neutrons (T-amplitudes within channels 180 and 400): 60.

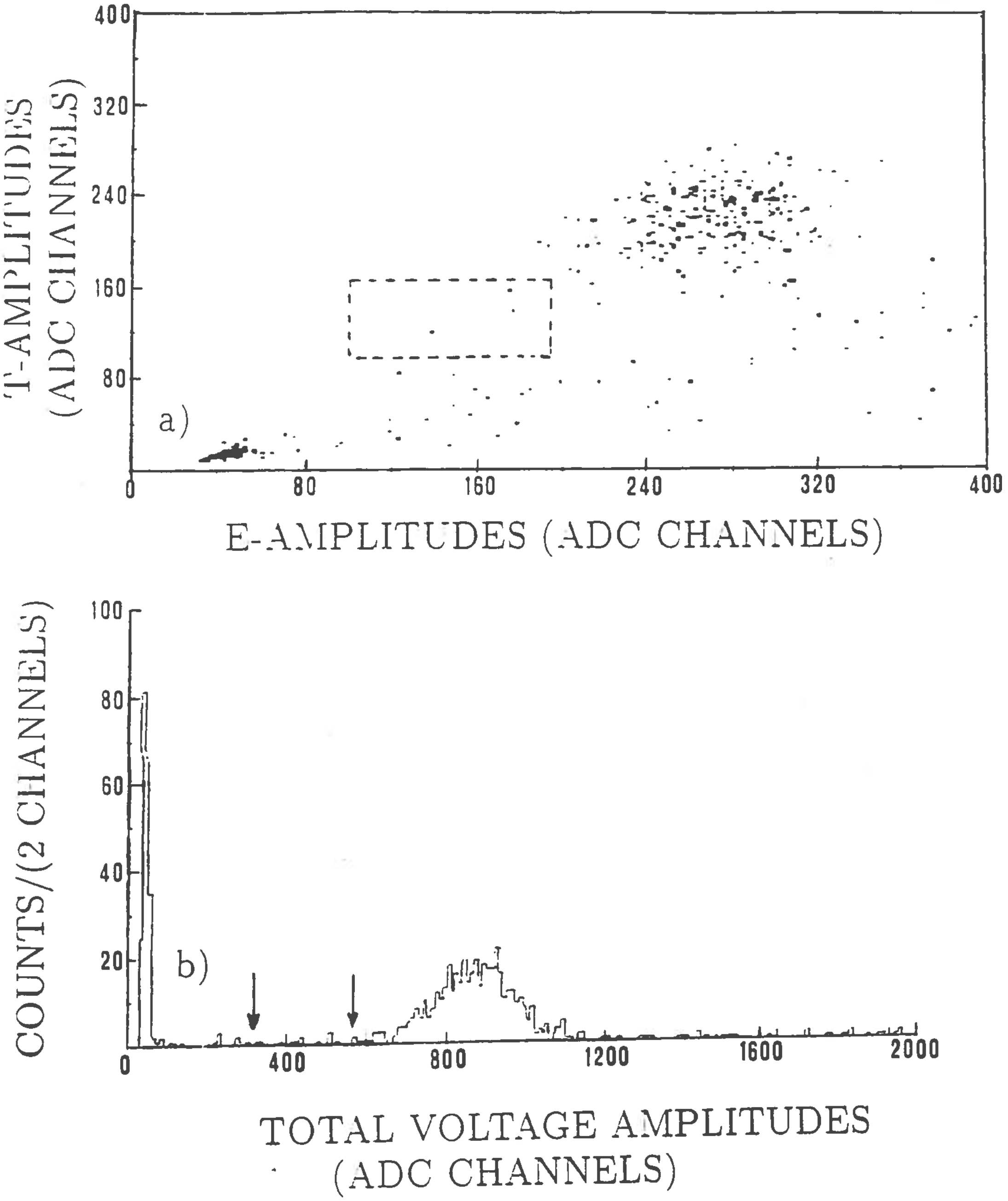

Fig. 5 - Delayed pulses amplitude distribution for the background measurement of Fig. 4. ***(a)*** (E,T) plot of the delayed signals. Total number of events: 448. The dashed rectangle shows the cuts suggested by Fig. 3a) to select neutron amplitudes. ***(b)*** Total amplitude (voltage) distribution of the delayed signal. The arrows show the cuts performed on the events of Fig. 3b) to select neutrons.

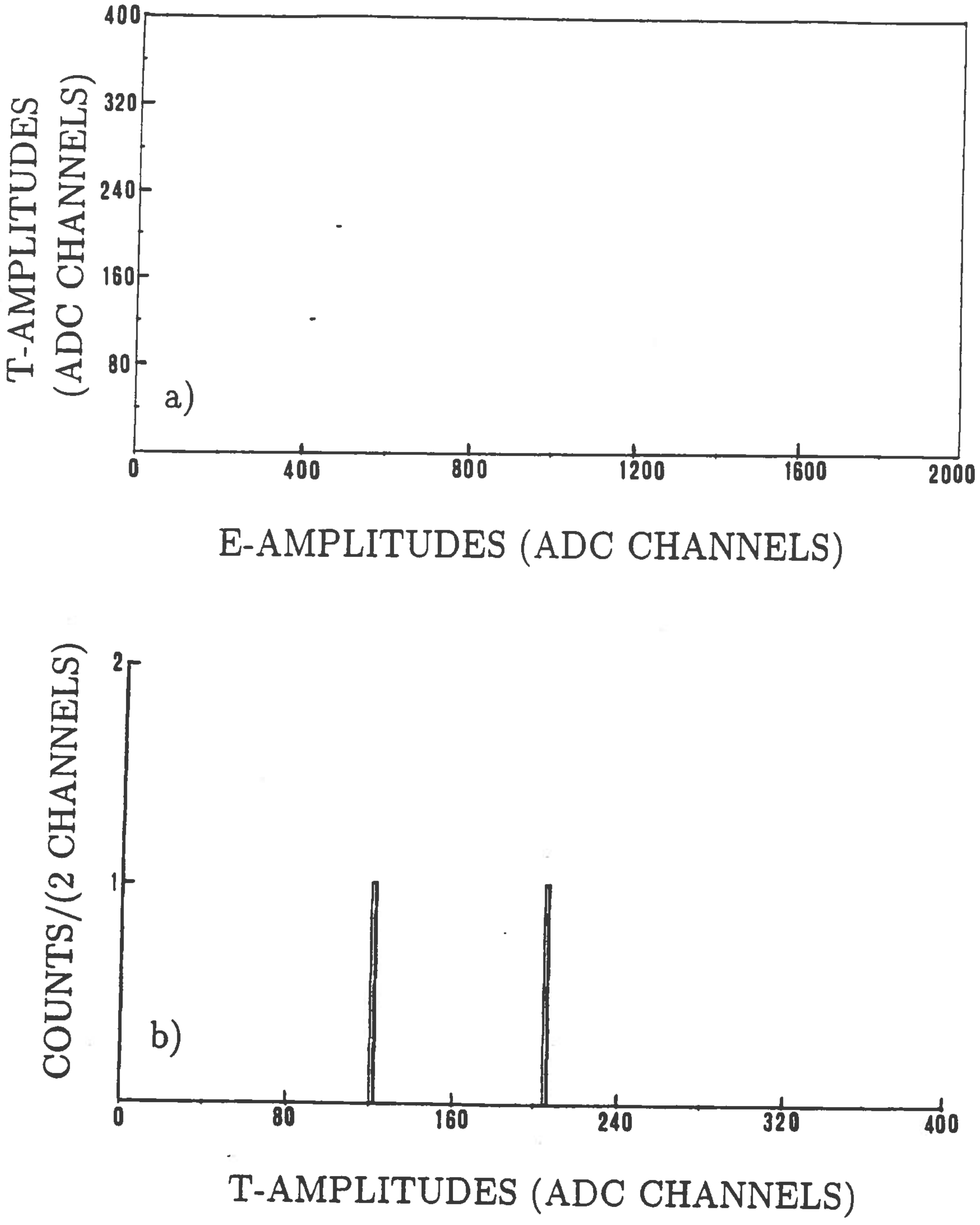

Fig. 6 - Results obtained for the background run of Fig. 4 after the coincidence request, and E-amplitude cuts (333,989), T-amplitude cuts (180,400) for the prompt signals; E-amplitude cuts (100,190), T-amplitude cuts (100,165), and total voltage amplitude cuts (260,600) for the delayed signal amplitudes. (**a**) (E,T) plot of the prompt pulses; (**b**) T-amplitude distribution of the prompt pulses.