IEEE Transactions on Nuclear Science, Vol.NS-22, February 1975

AN ARGON GAS SCINTILLATION COUNTER WITH UNIFORM ELECTRIC FIELD

C.A.N. Conde, M.C.M. Santos, M. Fátima A. Ferreira
and Célia A. Sousa

Departamento de Física, Universidade de Coimbra
Coimbra - Portugal

Abstract

A new type of gas proportional scintillation counter with uniform electric field is described. This counter is the scintillation counter analog of the Frish ionization chamber. Its principle is discussed and the properties experimentally studied using pure argon. Energy resolutions of 1.9% were obtained for 8.1 MeV alpha particles. Some results concerning the interpretation of the mechanism of the secondary scintillation are discussed.

Introduction

The study of the scintillation output of noble gas scintillators with an applied electric field has been the subject of recent work[1-16]. The scintillation output that can be obtained with no field (the so-called pure or primary scintillation) can be increased by two or three orders of magnitude[3] when an electric field is applied. The increased light output (the so-called secondary scintillation) although slow (rise times of a few microseconds are typical) when compared to the primary scintillation (typical rise times are of the order of a few tens of nanosecond) can lead to a large improvement of the energy resolution of the scintillation counter[1-2]. Thus if the primary scintillation is used for timing and the secondary one for energy resolution purposes, a powerfull tool is obtained for application in those fields of nuclear radiation spectroscopy where gas counters are preferable to solid state counters.

The energy resolution obtained depends not only on the factors related with the amount of light produced (namely the statistical fluctuations in the number of photoelectrons released in the photocathode) but also on the geometry of the electric field used to produce the secondary scintillation. This light is produced when the electrons resulting from the primary ionization process, travel towards the anode and excite in their path the molecules of the gas (for strong enough electric fields there will be also ionization).

To obtain an amount of secondary scintillation proportional to the energy of the incident radiation as well as a good energy resolution a general principle has to be obeyed: the amount of secondary light produced must be independent of the point in the sensitive region of the counter where the nuclear radiation interacted with the scintillation gas. Otherwise identical events would produce different amounts of light. This principle implies that the region of the gas where the secondary scintillation is produced must be a small portion of the counter total sensitive volume.

Such conditions can be easily obtained with a cylindrical geometry electric field in a detector of the type of the proportional counter. Here, only in a small volume around the central anode is the electric field strong enough to **produce secondary** scintillation. This lead to the development of the so-called cylindrical gas proportional scintillation counter[1-4]. In this counter an energy resolution similar to the proportional counter one (3 or 4% for 8 MeV α-particles) has already been obtained. However, this gas proportional scintillation counter seems to have, at least for α particles, poor linearity.

Spherical geometries have also been studied[7]. In this case a resolution of 8.5% was obtained for X rays with energies as low as 5.898 keV.

Uniform field geometries have been the subject of intensive studies[8-16]. This geometry is the ideal to study the mechanism of the secondary scintillation. However some of the results obtained do not show an apreciable improvement in the energy resolution. The best resolution quoted for uniform fields is around 10% for α particles[10-11]. The apparent reason for so poor results lies on the fact that the geometries used do not obey the referred to above principle: production of light being limited to a small volume of the counter. (Instead), for those geometries, the α particles are injected in the region of the field where the secondary scintillation is produced. Thus, as the amount of secondary light is proportional to the length of the path travelled by the electrons in field, α particles with the same energy but different orientations will produce different amounts of secondary light, which implies a deterioration of the energy resolution. Also, due to the fact that particles with different energies have different ranges, the amount of light produced will also depend on the particle range. This effect will lead to a lack of energy linearity.

In the counter to be described in the present work - <u>The Uniform Field Gas Proportional Scintillation Counter</u> - these inconvenients have been avoided. The energy resolution obtained, 1.9% for 8.1 MeV α particles, is superior to any figure so far quoted for gas scintillation counters with uniform electric fields and is even superior to the best resolution quoted for any kind of α particle scintillation counter with organic, halide or gaseous type scintillators. The energy linearity we obtained is better than 1%.

A preliminary description of this counter has already been made[13-15]. Another counter of this type[16] has been described recently and used for X ray detection with an energy resolution equal to the spherical gas proportional scintillation counter[7] one.

The uniform field gas proportional scintillation counter

Principle

The uniform field gas proportional scintillation counter consists of two parallel grids close to each other in a recipient filled with a scintillation gas, as indicated in Fig. 1. Grid 2 at a potential of a few hundred Volts, V_2, produces a field of a few tens of Volt/cm in the main volume of the counter (region between grid 2 and the counter top wall). Grid 1 being at a high voltage (1 or 2 kV), V_1, and close to grid 1, produces a strong electric field of a few kV/cm in the region between the two grids. These two regions are called, henceforth, weak field and strong field region, respectively. To obtain a fairly uniform electric field in the weak field region a set of two field rings, properly polarized through a chain of resistors, is used.

When an α-particle enters the weak field region through the counter window, it produces along its path electrons that, due to the field, drift towards grid 2. As the field is too weak they will not acquire, between collisions, enough kinetic energy to ionize or even excite the gas molecules and so there will be no light produced, besides the one that arises during the primary scintillation processes. But, when these electrons reach the strong field region they will get enough energy to excite the gas molecules and so an amount of light (secondary scintillation) proportional to the number of electrons initially produced will arise. The light output is then independent on the location of the α-particle track and is proportional to the energy dissipated inside the counter. The predominantly ultraviolet light spectrum of the secondary scintillation is shifted towards the sensitive region of the photomultiplier by a thin film of wavelength-shifter (p-quaterphenyl) deposited onto the counter optical (quartz) window. As the secondary scintillation is produced in the strong field region, and so close to the photocathode of the photomultiplier, variations in the light collection efficiency due to solid angle effects are minimized.

This counter obeys the general principle discussed above and is, in a way, the scintillation counter analog of the Frish ionization chamber.

Experimental system

The uniform field gas proportional scintillation counter used in this work is shown in Fig. 2. The counter is made of brass with a Melinex entrance window 1.616 mg/cm^2 thick. The separate parts of the counter are either silver soldered or joined with indium gaskets.

The two grids are made of nickel mesh and are of the E.M.I. type with 80 cells/inch. They were glued with Araldite to thin brass rings which are held in position with Teflon insulators. The distance between the grids can be varied by the use of Teflon spacers with different thicknesses. The actual distance used in the present work was 3mm. A 200 μg/cm^2 thick p-quaterphenyl deposit was vacuum evaporated onto the quartz (Spectrosil A) window. An RCA 8575 photomultiplier with silicon fluid optical coupling, and a 470 kΩ anode resistor was used to detect the light pulses. The two grids were polarized through 4MΩ resistors. The counter was filled with commercial argon (purity 99.99%) at a pressure of 1264 Torr which was purified in a continuous circulation system with calcium turnings at 320 °C, in a system similar to the on described before[2]. A ThB-ThC' α particle source was used throughout this work. After passing the Melinex window the two α particle groups had their energies reduced to 8.1 and 5.0 MeV.

Experimental results and discussion

Pulse shapes

Both, photomultiplier pulses and charge pulses (taken from grid 1) have similar shapes and a slow rise time of about 20 or 30 μsec, which indicates that, as expected, the secondary scintillation is produced when the electrons released by the incident α particle travel towards the grids; the slow rise time is characteristic of pure argon and it is due to the slow transit time of electrons in this gas. The weak primary scintillation pulse that should arise in pure argon was observed with difficulty, perhaps due to the small solid angle by which the photomultiplier sees this scintillation.

Pulse amplitudes and linearity

For the range of voltages used in this work for grids 1 and 2, we observed no appreciable variation in the amplitude of the charge pulses taken from grid 1. This shows that the electrons never acquire enough kinetic energy to ionize the gas and so the counter works always in the ionization chamber region.

As it was indicated in section 2, we expect no secondary light production in the weak field region and a fairly large amount of light in the strong field one. This implies that the total amount of secondary light shall depend only on the difference between the potential of grid 1, V_1, and that of grid 2, V_2. To study this effect we have plotted in Fig. 3 the secondary scintillation pulse amplitudes, for the two α particle groups, versus V_1-V_2 for potentials V_2 equal to 200 and 400 Volts. As expected the curves are practically coincident, as they were for other potentials (unplotted). Only for voltages larger than about 400 Volts there is production of secondary scintillation. To this voltage corresponds an electric field between the grids of about 1300 Volts/cm and a reduced field (E/p) of about 1 Volt/cm/Torr. This is in agreement with the figure calculated by Braglia et al.[17-18] for the minimum reduced field that can produce secondary scintillation in xenon.

For voltages V_1-V_2 between about 700 and 1600 Volts the amplitude of the secondary scintillation is approximately proportional to V_1-V_2. The maximum value of V_1-V_2 was limited by sparking between the grids.

For reference purposes the amplitude of the photopeak of a ^{137}Cs 661 keV gamma source from INa(Tl) crystal coupled to the photomultiplier we used is also indicated in Fig. 4.

The ratio of the amplitudes of the pulses for the two α particle groups must be equal to the ratio of the energies dissipated inside the counter, i.e. 1.62, which is within 1% of the experimental value. The deviations from linearity can be attributed to differentiation of the slow pulses by the "fast" (≃50 μsec) time constant of the preamplifier. The 1% figure represents a improvement over the cylindrical gas proportional scintillation counter linearity.

Energy resolution

To the increased amount of light produced in the secondary scintillation processes must correspond an improvement in the energy resolution. Actually such a behaviour is observed and the well know variation law (the square of the resolution proportional to the inverse of the pulse amplitude) is followed[15]. Fig. 4 shows a spectrum with an energy resolution of 2.1% for 8.1 MeV α particles. The best resolution obtained was 1.9% under conditions similar to the ones indicated in Fig. 3. Further improvement on the energy resolution seems likely. All the results shown here are reproducible.

Concluding remarks

In this work we have developed an argon uniform field gas proportional scintillation counter, which shows good energy resolution for α particles. The results obtained so far encourage the endeavour of further research mainly in the fields of X ray, β and γ spectroscopy as well as neutron and fission work. The fact that argon is an inexpensive gas might increase the range of applications to fields like internal gas counting. The inconvenience of the slow rise time can be, in principle, reduced by the use of stronger fields in the weak field region.

The experimental study of gases other than argon, like xenon and its mixtures, might show an improvement in the energy resolution.

We thank Professor J.R. de Almeida Santos for his encouragement. This work was possible due to the financial support given by Instituto de Alta Cultura (Project CF/2).

References

1 - C.A.N. Conde and A.J.P.L. Policarpo, Nucl. Instr. Meth. 53 (1967) 5.

2 - A.J.P.L. Policarpo, M.A.F. Alves and C.A.N. Conde, Nucl Instr. Meth. 55 (1967) 105.

3 - A.J.P.L. Policarpo, C.A.N. Conde and M.A.F. Alves, Nucl. Instr. Meth. 58 (1968) 151.

4 - C.A.N. Conde, A.J.P.L. Policarpo and M.A.F. Alves, IEEE Trans. Nucl. Sci. NS-15, nº 3 (June 1968) 84.

5 - A.J.P.L. Policarpo, M.A.F. Alves, M.J.T. Carvalho and M.A.G. da Rocha, Nucl. Instr. Meth. 77 (1970) 309.

6 - A.J.P.L. Policarpo, M.A.F. Alves, M.J.T. Carvalho and M.A.G. da Rocha, Nucl. Instr. Meth. 96 (1971) 487.

7 - A.J.P.L. Policarpo, M.A.F. Alves, M.C.M. dos Santos and M.J.T. Carvalho, Nucl. Instr. Meth. 102 (1972) 337.

8 - J.-L. Teyssier, D. Blanc and A. Godeau, "Electronique Nucléaire-1963" (Agence Européene pour l'Energie Nucléaire, 1964) pg. 43.

9 - J.-L. Teyssier, D. Blanc, J. Brunet and A. Godeau, Nucl. Instr. Meth. 30 (1964) 331.

10- J.-L. Teyssier and D. Blanc, L'Onde Elec. 44 (1964) 458.

11- D. Blanc, L. Commanay and J.-L. Teyssier, L'Onde Elec. 49 (1969) 796.

12- F. Labernede, J. Galy, D. Blanc and J.-L. Teyssier, Int. Symposium on Nuclear Electronics - Versailles, Paris 1968, vol. I, pg. 10-1.

13- M. Fátima A. Ferreira, "Estudo de um contador gasoso de cintilação com campo eléctrico uniforme", University of Coimbra, Physics Department, internal report, 1971 (unpublished).

14- Célia A. Sousa, "Estudo de um contador gasoso de cintilação de campo eléctrico uniforme com argon", University of Coimbra, Physics Department, internal report, 1973 (unpublished).

15- M. Fátima A. Ferreira, Célia A. Sousa, Cidálio Cruz, Lucília P. de Brito, Rui F. Marques and C.A.N. Conde, "Estudo de um contador de cintilação de resolução elevada com argon puro e campo eléctrico uniforme", Communication presented to the "XXXI Congresso Luso-Espanhol para o Progresso das Ciências", Cadiz - April 1974.

16- H.E. Palmer and L.A. Braby, Nucl. Instr. Meth. 116 (1974) 587.

17- G.L. Braglia, L. Gabba, F. Giusiano, G.M. De'Munari and G. Mambriani, "Il Nuovo Cimento" 56-B 283 (1968).

18- G.L. Braglia, G.M. De'Munari and G. Mambriani, "Il Nuovo Cimento" 43-B, 130 (1966).

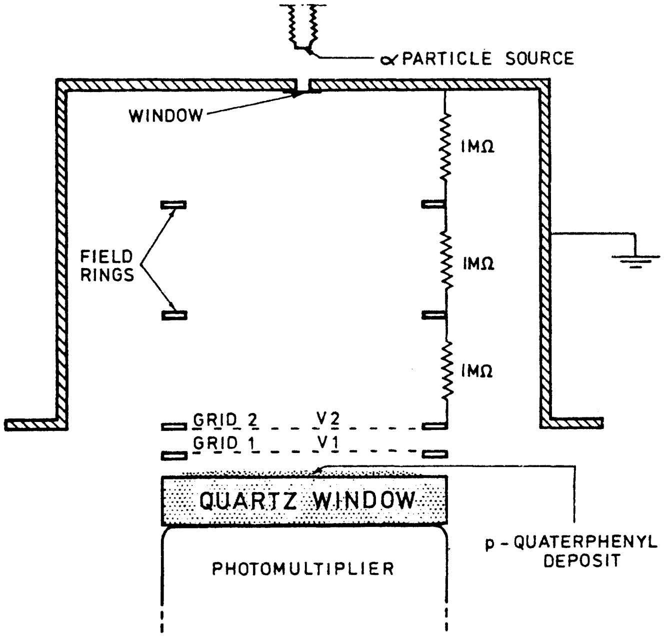

Fig. 1 - Schematic diagram that shows the principle of the uniform field gas proportional scintillation counter.

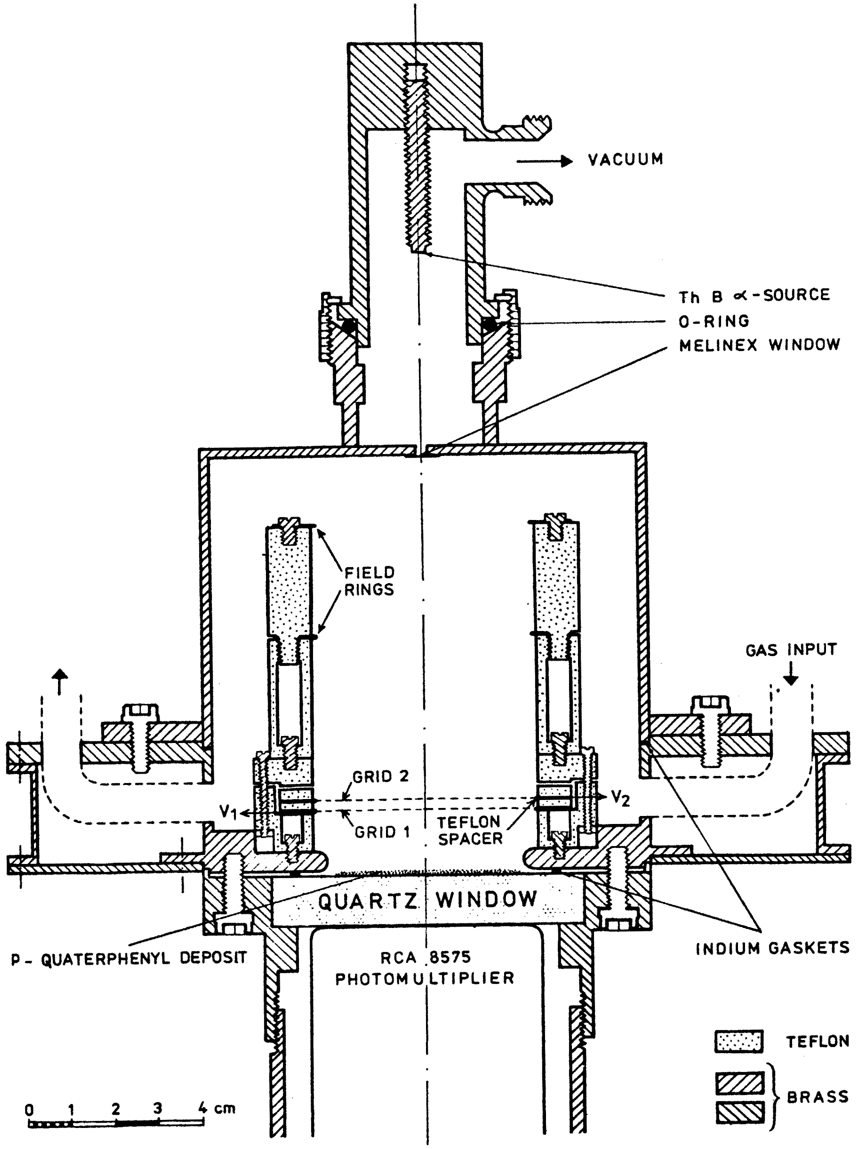

Fig. 2 - Cross section of the uniform field gas proportional scintillation counter.

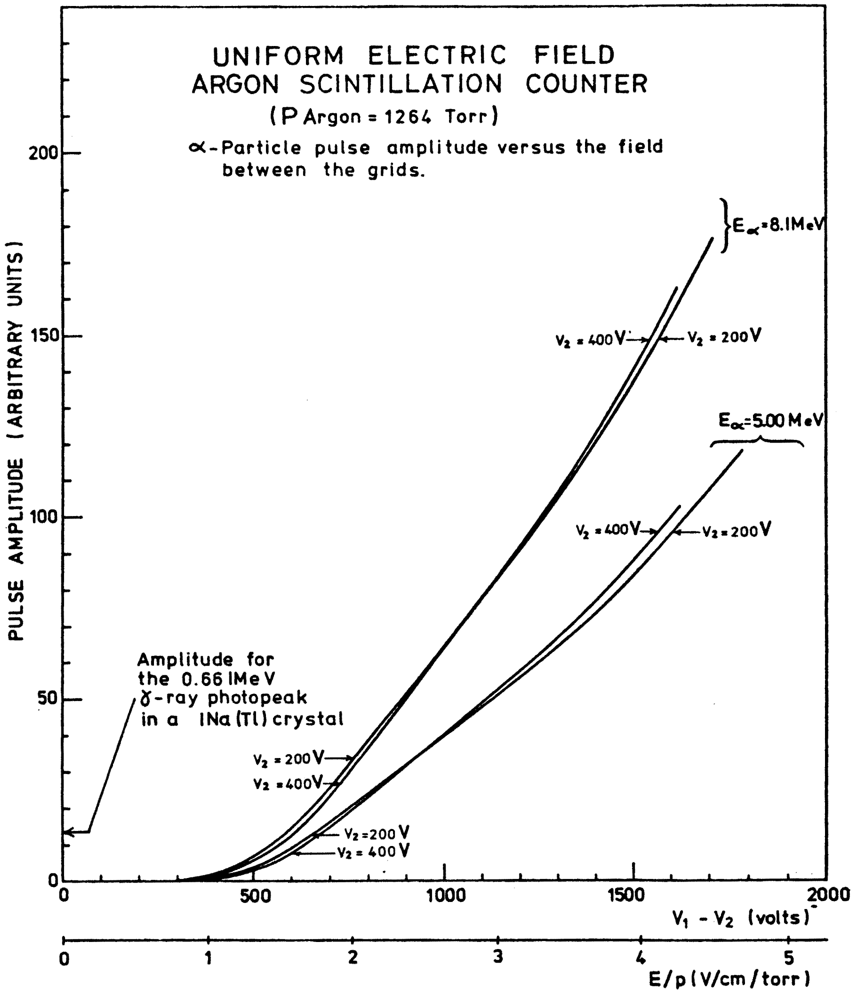

Fig. 3 - Variation of the secondary scintillation pulse amplitude with the difference of potential between the grids (and the reduced electric field: E/p) for argon at 1264 Torr.

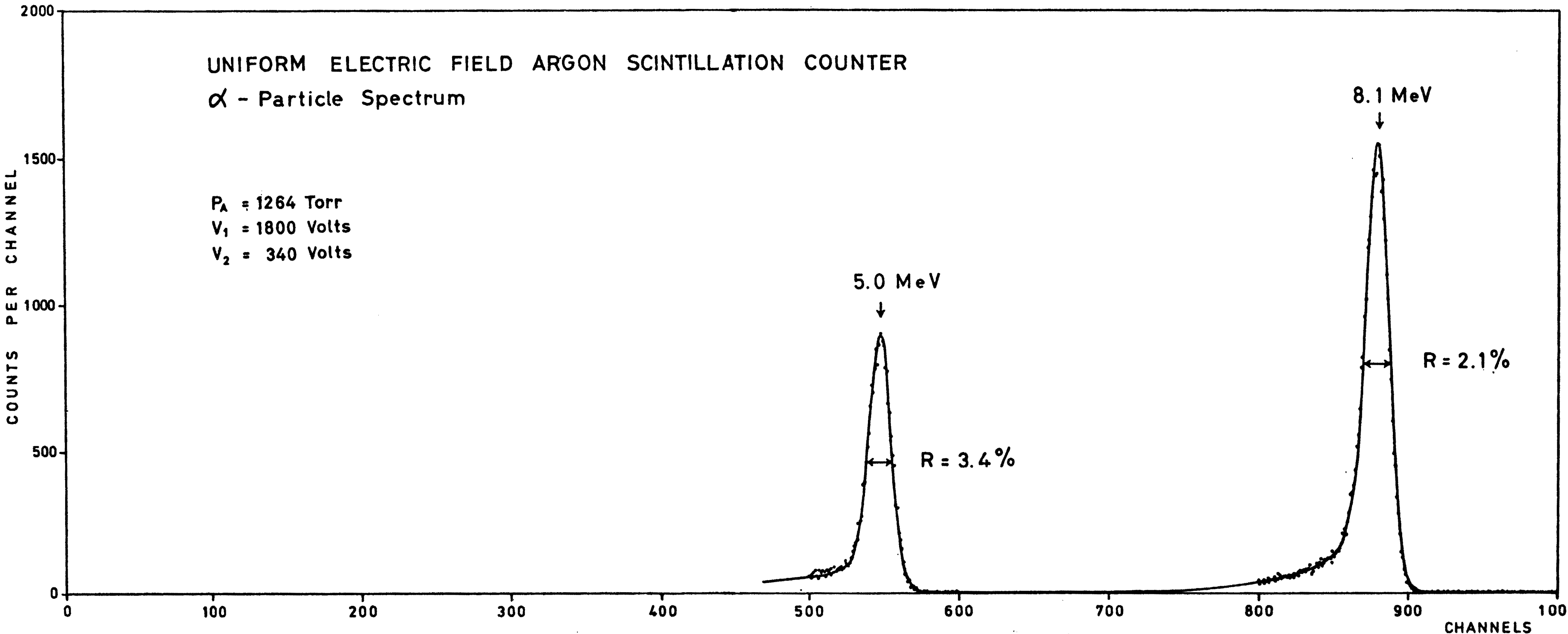

Fig. 4 - Argon uniform field gas proportional scintillation counter α particle spectrum.