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ABSTRACT

The delayed gamma-ray emission in ^{252}Cf spontaneous fission has been studied using a lithium drifted germanium detector. In the time range 300 nanoseconds to 5 microseconds after fission a number of gamma rays were seen and their half-lives and intensities were measured. The results are compared with a recent investigation which used a different experimental method.

Note: This paper has been submitted to a journal. Further details can be obtained from the author or the Director of the Research Establishment.

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1. INTRODUCTION

Most of the excitation energy of fragments formed in fission is given up in the form of neutrons and gamma rays emitted promptly, i.e. within 10^{-11} seconds after the formation of the fragments. This leaves the fragments in various isomeric states from which they decay to their ground states by emission of the so-called delayed gamma-rays. The half-lives of these delayed gamma-rays range from a few nanoseconds to several microseconds (Johansson 1965, Popeko et al. 1966, Walton and Sund 1969). Some fragments are beta unstable and give rise to long-lived betas, delayed neutrons and related gamma rays with half-lives ranging from a few seconds to many days.

Low resolution gamma-ray detectors (Johansson and Kleinheinz 1965) have been used in most of the work on prompt gamma-ray emission. However, in 1969 Watson et al. used a high resolution, lithium drifted germanium detector to determine the energies, half-lives and emitting fragment mass assignments of these prompt gamma-rays and very recently Guy (1970) made a corresponding study of the delayed gamma-rays arising from ^{252}Cf spontaneous fission.

The present paper reports a similar investigation using a very different experimental method. The object was to verify the energies, half-lives and intensities of the long-lived gamma-rays as reported by Guy.

2. EXPERIMENTAL PROCEDURE

The experimental system is shown schematically in Figure 1. Gamma-ray spectra were recorded as a function of the time after fission. The gamma-rays were detected with a 10.7 cm^3 coaxial lithium drifted germanium diode which had a 3.5 keV energy resolution (FWHM) for 661 keV gamma-rays from ^{137}Cs decay. The photo-peak detection efficiency of the detector at various gamma-ray energies was calibrated with standard sources. Fission events were recorded in a shallow argon-methane gas flow ionisation chamber which was mounted on the face of the gamma-ray detector to maximise the delayed gamma-ray detection efficiency. The ionisation chamber was of parallel plate construction in which a small plate spacing of 0.7 cm was used to improve the discrimination between the fission fragments and alpha particles from the source.

The ^{252}Cf source was deposited on a thin nickel foil which together with its stainless steel supporting ring formed the cathode of the ionisation chamber. The spontaneous fission rate of the source was 2.05×10^5 min^{-1}.

The logic of the electronics is shown in Figure 2. Discriminators were set on the gamma-ray line to respond to amplified signals corresponding to energies in excess of 50 keV and on the fission fragment line, to reject the natural alpha activity of the source. Timing data were obtained from a time to amplitude converter (TAC) triggered by the fission pulse and stopped by the fast signal accompanying gamma-ray detection. The timing data and linear gamma-ray pulse height data were fed to a PDP–7 on-line computer operated as a two parameter analyser. The time parameter was divided into six equal intervals of 0.79 μsec each by means of digital windows, and the delayed gamma-ray data in coincidence with the TAC signals were recorded in the appropriate region of 1024 channels corresponding to the time interval. Zero time for the time parameter corresponded to 0.3 μsec after fission.

It was important to minimise background in the gamma-ray detector in view of the low yield of the fission isomers. The reduction of environmental background by lead shielding of the gamma-ray detector increases the time dependent background because of the detection of prompt fission neutrons which have a lifetime in the shielding assembly. The experiment was therefore performed in a low background area where the shielding material in proximity to the gamma-ray detector could be substantially reduced. The main source of background in the gamma-ray detector was then the detection of prompt gamma-rays associated with a second random fission event occurring during any of the six time windows. Since the fission counter had an efficiency greater than 95 per cent this form of background was substantially reduced by using the fission signal to inhibit the fast gamma-ray line for 300 nsec. Figure 3 shows the effectiveness of the inhibit unit in removing the prompt component from the time spectrum. Figure 3 also shows that the experimental time resolution is of the order of 55 nsec.

Four separate runs each of about 4 x 10^6 coincident events (timing and gamma-ray pulse-height data) were recorded. The typical coincidence count rate was 50 sec^{-1} of which about 5 per cent was due to chance coincidences. A timing calibration was made before and after each run by introducing known delays and the gamma-ray energy scale was also checked before and after each run using standard sources. Two further measurements, with and without a 0.8 cm thick lead absorber between the ionisation chamber and the gamma-ray detector, were made to determine the gamma-ray lines arising from neutron capture in the detector.

3. RESULTS AND DISCUSSION

3.1 Data Analysis

The raw data from the PDP–7 data collection system were transferred to magnetic tape (via paper tape) for analysis by an IBM 360 computer. A least squares smoothing program removed the background continuum from each of the six spectra and the results for one of the four runs are shown in Figure 4. The peak intensities were determined simply by adding the counts in each peak. The error was taken to be the statistical error on the total number of counts in the continuum and the peak. A simple exponential fitting program was used to determine the half-lives of the various decaying gamma-rays. A typical fit for the 326.3 keV line is shown in Figure 5. The yield per fission was calculated from the observed intensity by using the absolute detection efficiency, the total number of fission events and the half-life for each gamma-ray.

3.2 Corrections

The calculation of absolute yield per fission involved corrections for source spread (the fragments emit the gamma-rays after traversing nearly 0.5 cm before being stopped by the anode plate and the walls of the ionisation chamber) dead time losses in the analyser, and prompt gamma shielding (that is, events where both the prompt gamma-ray and the ensuing delayed gamma-ray are detected but not recorded because of the electronic inhibit unit). As these corrections are difficult to estimate, only the relative yields for the various gamma-rays have been calculated from the gamma detection efficiency, total number of fission events and the half-lives.

3.3 Results

Table 1 gives the energies, half-lives and intensities averaged over the results obtained for the four experimental runs and compares them with the results of Guy (1970). The intensities have been normalised to obtain agreement for the 131.1 keV line. The energies agree within 1 keV and the half-lives within 10 per cent (except for the 122.4, 142.2 and 192.2 keV lines). The intensities are of the same order of magnitude.

Guy reported delayed gamma-rays of energies 111.2, 169.8, 140.9, 158.0, 100.7, 111.0, 186.4, 225.7, 96.5 and 162.5 with respective half-lives 3000, 440, 360, 1500, 530, 760, 650, 1500, 2100 and 2100 nanoseconds, and low intensities of the order of 4 x 10^{-4} photons per fission. Of these only the 169.8 and 225.7 keV lines could be resolved in the present experiment, presumably owing to lack of fragment mass information. Guy also obtained 86.3, 153.6 and 197.3 keV lines with respective half-lives of 140, 110 and 2800 nanoseconds and fairly high intensities ($\sim$60 x 10^{-4} photons per fission). These lines were also identified in the present experiment although the data did not permit a proper analysis of their intensities and half-lives. The present data indicate the presence of some very long lived components (>10 microseconds half-life) with energies of 276, 281 and 294 keV respectively which have not been reported earlier.

4. CONCLUSION

The present work largely confirms the results of Guy (1970) who used a different experimental technique, but more work is required to resolve serious discrepancies in the half-lives and intensities of some of the lines.

5. ACKNOWLEDGEMENTS

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TABLE 1

FINAL RESULTS FOR AVERAGE OF FOUR RUNS

S. No.	E_γ (keV)		$T_{1/2}$ (nsec)		Yield per 10^4 Fission	
	Present	Guy	Present	Guy	Present	Guy
1.	66.2	66.2	< 200	140 ± 14	–	60 ± 6
2.	96.7	96.2	600 ± 20	550 ± 40	74 ± 4	80 ± 7
3.	115.2	115.0	<250	162 ± 12	–	61 ± 4
4.	122.4	121.4	2240 ± 700	360 ± 36	12 ± 5	48 ± 5
5.	131.1	129.8	370 ± 30	340 ± 50	29 ± 3	29 ± 4
6.	142.2	141.7	690 ± 130	1400 ±140	3 ± 1	9 ± 1
7.	172.1	170.5	1570 ± 250	1100 ±220	8 ± 1	20 ± 4
8.	192.9	191.6	1800 ± 210	850 ±140	13 ± 2	14 ± 3
9.	205.5	204.0	>4000	~ 3000	–	–
10.	326.7	324.5	630 ± 50	570 ± 50	25 ± 2	31 ± 3
11.	383.5	380.7	3380 ± 350	3400 ±270	39 ± 9	73 ± 6

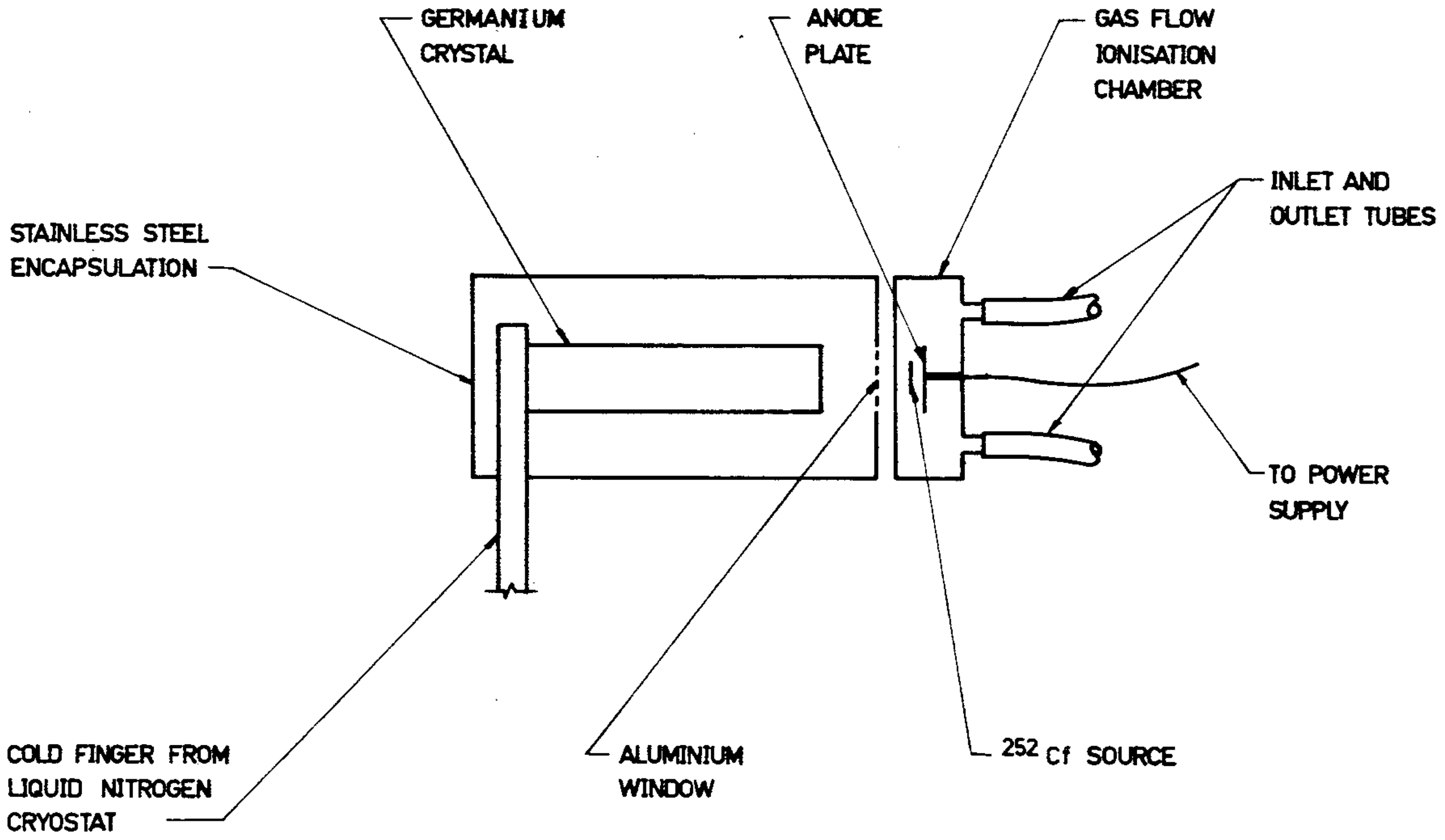

FIGURE 1. SCHEMATIC DIAGRAM OF THE EXPERIMENTAL ASSEMBLY

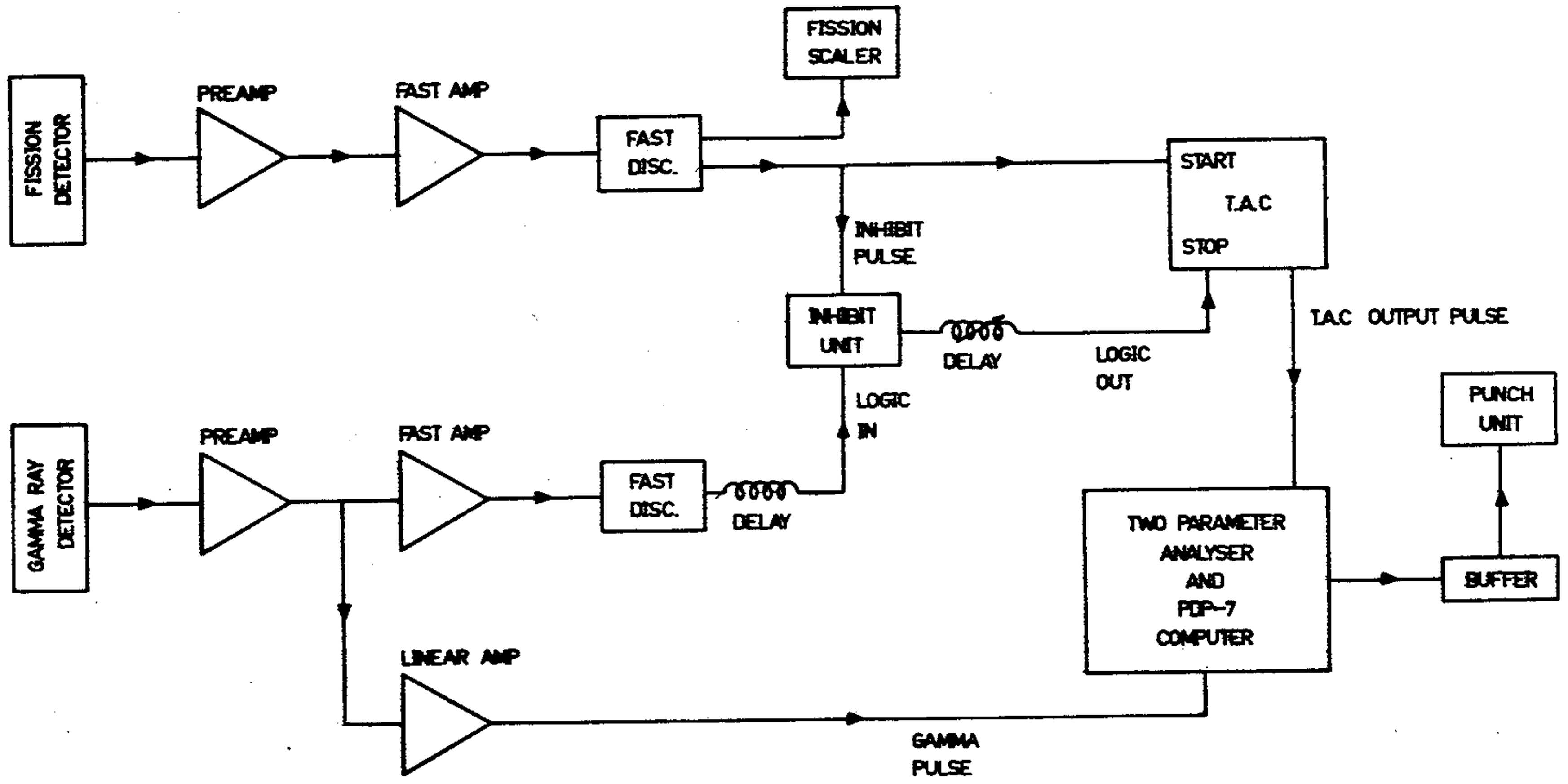

FIGURE 2. BLOCK DIAGRAM OF THE ELECTRONICS

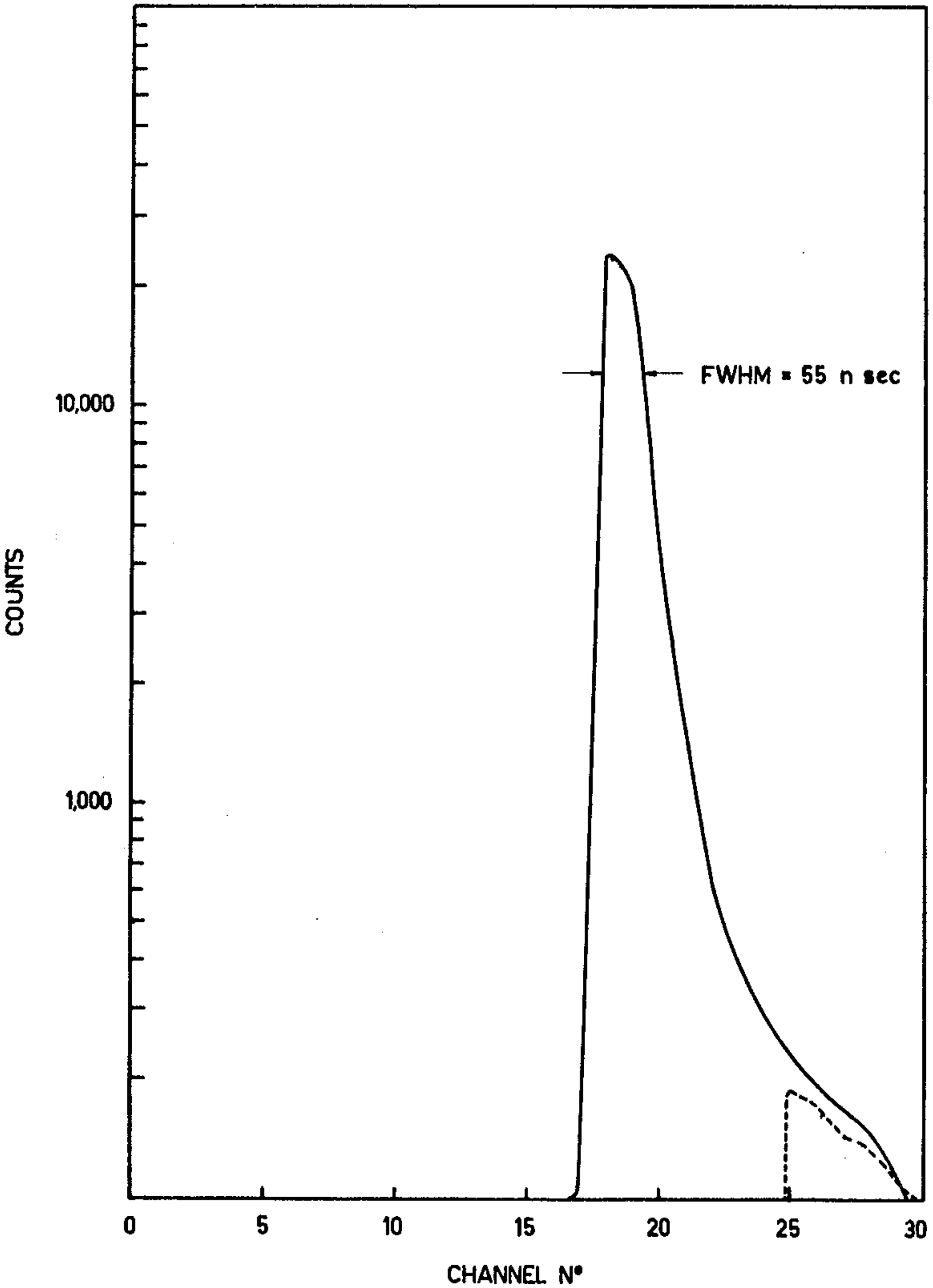

FIGURE 3. TIME TO AMPLITUDE CONVERTER OUTPUT WITH, (dotted line) AND WITHOUT THE INHIBIT REQUIREMENT

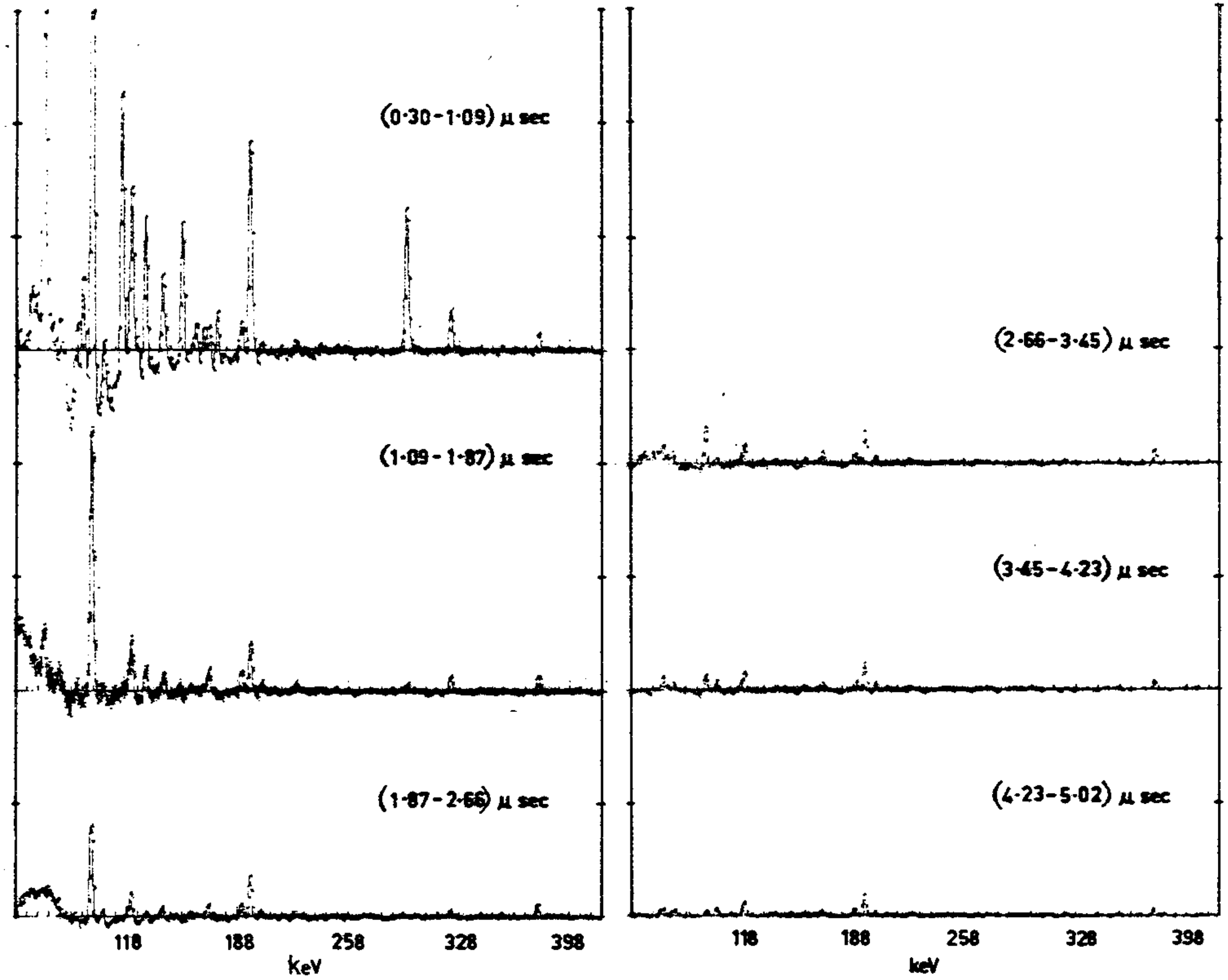

FIGURE 4. ONE SET OF CONTINUUM SUBTRACTED SPECTRA FOR SIX CONSECUTIVE TIME INTERVALS OF 0.79 MICROSECONDS EACH

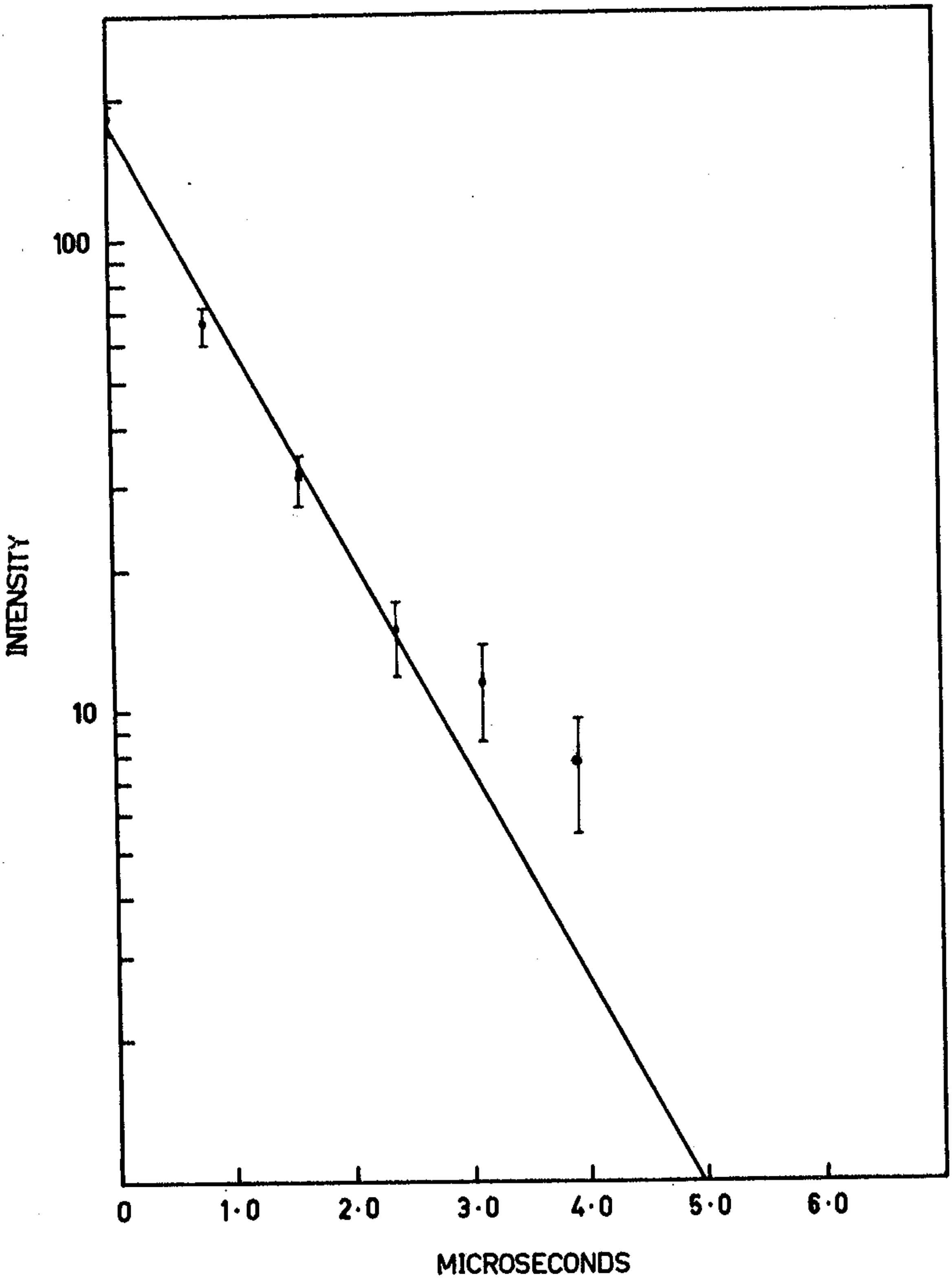

FIGURE 5. EXPONENTIAL FIT TO THE DATA FOR THE 326.3 keV LINE