GAMMA RAYS RESULTING FROM NEUTRON

SCATTERING IN CESIUM

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THESIS

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

The nuclear energy levels of Cs^{133} have been studied by various methods with the earliest investigations based on studies of the decay of Ba^{133} (1, 2, 5, 7, 9, 10, 14). An excited Cs^{133} nucleus is produced when a Ba^{133} nucleus decays by electron capture and the nucleus then decays to the ground state through a single transition or a series of transitions, with each transition emitting a gamma ray. By studying the energies of these gamma rays, the energy levels of cesium can be determined. However, the highest energy level to which Ba^{133} decays is 0.44 Mev, and therefore it is desirable to study Cs^{133} by a method that will excite higher levels.

Bombarding the nucleus with different types of particles will excite the nucleus. In the case of cesium, two different bombarding particles have been employed. The first, known as Coulomb excitation (4, 12, 13), uses alpha particles as the bombarding particles. These alpha particles have insufficient energy to enter the nucleus, but the interaction between the Coulomb fields of the target nucleus and bombarding particle is sufficient to excite the nucleus. The nucleus then decays by emission of gamma rays, and the energies of these gamma rays are in agreement with those found

in the decay of Ba^{133}, although the study by Coulomb excitation has not been as thorough as that with decay of Ba^{133}.

In this study, neutrons are used as bombarding particles. Since the neutron has no charge, it can enter the nucleus, form a compound nucleus of short half-life, and emerge from the nucleus with less energy, leaving the target nucleus in an excited state. This method, known as inelastic scattering of neutrons, has been used previously to study Cs^{133} (3, 6, 8, 15). Young (15) used 14 Mev neutrons produced by a D (t,n) He^4 reaction, Lamb (6) used 2.5 Mev neutrons produced by a D (d,n) He^3 reaction, and McDonald (8) and Dawson (3) used both 2.5 Mev and 14 Mev neutrons. The present study uses only 14 Mev neutrons produced in a D (t,n) He^4 reaction, where the deuterons are produced and accelerated in the North Texas State University Cockcroft-Walton accelerator.

In the previous cases (3, 6, 8, 15) of studying the energy levels of Cs^{133} by inelastic scattering of neutrons, the scatterer was a CsI(Tl) scintillation crystal that served both as a scatterer and detector. This investigation uses CsCl as the scatterer and two types of detectors for the gamma rays. First, a NaI(Tl) scintillation detector was used, and, in an attempt to obtain improved resolution, a Ge(Li) solid state detector was used.

Inelastic scattering of neutrons has the disadvantage of producing a high background count, and it was hoped that this problem could be accounted for by taking coincidence

counts between the gamma rays emitted in the de-excitation of cesium and the alpha particles produced in the D-T reaction. The alpha particle detector was placed so as to detect only alpha particles produced in the reactions producing the neutrons that pass through the scatterer (Figure 2); however, due to problems in the coincidence circuit, no data were taken using the coincidence technique, The alpha particle detector was used to normalize the gamma-ray spectra to the same number of neutrons passing through the scatterer.

The purpose of this investigation was to attempt to resolve the energy levels of Cs^{133} that can be excited by inelastic scattering of 14 Mev neutrons.

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CHAPTER II

ACCELERATOR AND INSTRUMENTATION

Accelerator

Several modifications were made in the North Texas State University Cockcroft-Walton accelerator for these investigations. The accelerator was angled around a cement block wall that serves as a radiation shield (Figure 2), enabling manipulation of the controls for the extraction voltage for the ion source, heater current for the palladium leak, beam focus voltage, and RF oscillator tube screen and plate currents by means of wooden rods without the use of the selsyn motors as described by McDonald (1). Although these controls were not altered after the operation was started, this provided a means for easily adjusting these variables to produce the desired beam currents (Figure 3).

A dropping-resistor bank (200 megohm) was connected in parallel with the power supply and was tapped at regular intervals to provide the high voltage for the plates of the accelerating column. Both the resistor bank and the accelerating column were purchased from Texas Nuclear Corporation.

The power supply described by McDonald (1) was replaced with a Universal Voltronics Corporation, Model No. BPO 160-11.

This power supply provides 0-160 kilovolts, but because of arcs that developed from the high voltage terminal of the accelerator to ground, the high voltage was operated at 100 kilovolts. This voltage is monitored directly by a meter, and by knowing the "bleeder" current through the dropping-resistor bank this meter can be checked. The meters provide checks on the power supply in case shorts develop.

The palladium leak for the purpose of admitting deuterium into the ion bottle was also purchased from Texas Nuclear Corporation. The heater current regulates the amount of deuterium admitted and is found to produce maximum beam currents when operated at one ampere.

The beam is focused by means of a variable voltage applied to one plate of the accelerating column. The beam current was found to increase as the focus voltage was increased; however, when the focus voltage reached approximately -5000 volts, an arc developed and therefore the focus supply was operated at -4500 volts.

Instrumentation

Three different detectors were utilized in these investigations. Gamma-ray spectra were taken with two different detectors. First, a Harshaw 1 1/2" by 1" NaI scintillation crystal was used with a Hamner high voltage power supply Model N-4035 and a preamplifier which was constructed

from Sturrup Corporation design. Representative spectra taken with the NaI crystal are shown in Figures 5 and 6.

A second type of detector was also used for gamma ray detection. The detector was a Nuclear Diode, Inc., lithium-drifted germanium detector, Type LG 4.0-5, and was used because of the better resolution obtainable with solid state detectors. Figure 2 shows the experimental arrangement used with this detector, including the liquid nitrogen container and the arrangement for holding the detector. A Tennelec Model TC 130 FET preamplifier and Heathkit Model IP 32 power supply were used in conjunction with this solid state detector. Figures 7 through 10 show gamma-ray spectra taken with the solid state detector with a bias voltage of 400 volts. The resolution of the NaI crystal on the 0.662 Mev peak in Cs^{137} was 8.55 per cent, and for the solid state detector it was 3.12 per cent on the same Cs^{137} peak.

The third type of detector was a Nuclear Diode, Inc., PL. 5-100-50H surface barrier detector used for detecting the 3 Mev alpha particles given off in the D (t,n) He^4 reaction. The toroidal (1/2" O.D., 3/8" I.D.) detector was used in conjunction with an Ortec Model 105 preamplifier and an Ortec Model 106 power supply. Through the physical arrangement of this detector (Figure 1), it was hoped that the alpha particle count monitored by this detector could be used as a means of normalizing the gamma-ray spectra

with respect to the neutron count, since for each neutron emitted toward the scatterer an alpha particle would pass through this detector.

The gamma-ray signal from the preamplifier was fed into a Sturrup Model 2801 linear amplifier, and the output of the linear amplifier was analyzed using a Nuclear Data 1024-channel dual-parameter analyzer, Model ND-150M (Figure 4). The analyzer was operated primarily over only 256 channels with controls adjusted so that maximum energy represented on a given spectrum was 1.0 Mev for the NaI crystal and 0.7 Mev for the Ge(Li) detector. However, the energy range was doubled by using 512 channels in order to search for possible higher energies.

The alpha-particle signal from the preamplifier was amplified with a Sturrup Model 2801 linear amplifier whose output was fed into a Sturrup Model 501 single-channel analyzer. The output of this analyzer, which served as a discriminator against noise, was fed into an Atomic Instruments Scale of 64 Model 101-M scaler, which operated in conjunction with an Electro-Pulse Inc. scaler and home-built register.

The neutron counter (Figure 2) was a Texas Nuclear Corporation Model 9120 neutron counter.

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CHAPTER III

EXPERIMENTAL PROCEDURE

Neutrons, accelerated by the North Texas State University Cockcroft-Walton accelerator, were produced by a D (t,n) He^4 reaction. The neutrons were inelastically scattered by three different types of scatterers: cesium chloride, sodium chloride, and sodium.

These scatterers were placed in similar aluminum toroidal containers. Gamma-ray spectra were taken using each of the scatterers, and a background count was taken using an empty container. The spectra of gamma rays for cesium is obtained by first subtracting the sodium spectrum from the sodium chloride spectrum and then subtracting the remaining chlorine spectrum from the cesium chloride spectrum. The different densities of sodium in the sodium scatterer and the sodium chloride scatterer are taken into account, and also the density difference of chlorine is accounted for in the cesium chloride and sodium chloride scatterers.

The counting time for each spectrum taken with the NaI crystal was approximately five minutes. Because of the better efficiency of the NaI crystal compared with the Ge(Li) detector, the spectra taken with the NaI crystal were of a shorter time duration. The gamma-ray spectra were normalized

by two methods. Both the alpha-particle detector and the neutron counter were used, and because of instability in the alpha-particle counting equipment, the neutron count was considered more reliable. The neutron counter was placed directly in line with the beam, two feet from the tritium target. The gamma-ray detectors were placed as shown in Figures 1 and 2.

Sources used for calibrations were Na^{22}, Co^{60}, Cs^{137}, Mn^{54}, and Ba^{133}. The Ba^{133} source provided an excellent calibration source since the barium decays to some of the same excited states of cesium which would be excited by neutron excitation.

CHAPTER IV

RESULTS AND CONCLUSIONS

Representative gamma-ray spectra obtained from these investigations are shown in Figures 5 through 10. The figures show the results of both the NaI detector and the solid state detector (Ge(Li)). In using the multichannel analyzer, it was found that the analyzer has an inherent discriminator. The cause of this discrimination was not investigated, but as a result peaks below 0.1 Mev are not discussed.

The background spectrum (Figure 5) for the NaI crystal is similar to that obtained by McDonald (8) and Dawson (3) by inelastic scattering of neutrons in a NaI crystal. The peak at 0.21 Mev is assigned to iodine since it does not appear in the background taken with the Ge(Li) detector (Figure 7). The peak has been reported by Dawson (3) and others (2, 7, 10). The 0.51 Mev peak which appears in both apectra is probably due to annihilation quanta induced in the background material. The other peak in the background taken with the NaI crystal at 0.165 Mev is not assigned. Dawson (3) observed a 0.16 Mev gamma ray and tentatively assigned it to sodium; however, a small peak appears in the Ge(Li) background at 0.155 Mev, and therefore no assignment is made.

The cesium spectrum taken with the NaI crystal (Figure 6) is complicated because of the subtraction process which

was used to obtain it. This process tends to deform some peaks because the background count cannot be normalized. All spectra used in obtaining the final cesium spectrum with the NaI crystal were normalized to 10,000 neutrons, but because of induced activity in the surrounding material, the background also varies. The spectra obtained by the subtraction are lower in the low energy range than would be expected because with the scatterer in place lower energy gamma rays produced toward the outer edges of the scatterer never reach the detector, due to self absorption; and since the background spectrum is taken without a scatterer, no self absorption occurs and the low-energy end of the spectrum is reduced in the subtraction process.

No attempt has been made to explain all of the peaks in Figure 6; however, it is noted that the peaks at 0.134 and 0.160 Mev appear also in the cesium spectrum obtained with the solid state detector. Since a few negative values appear, it is assumed that the background count was high and therefore false peaks could occur.

The gamma-ray spectra taken with the Ge(Li) detector are normalized to 70,000 neutrons. Each step of the subtraction process can be seen in the graphs with the Ge(Li) detector. First, the background is shown (Figure 7), then Figure 8 shows the spectrum obtained from subtracting the background from the spectrum taken with the sodium scatterer in place. The peaks in chlorine (Figure 9) are obtained by multiplying the sodium spectrum by a factor, to account

for the difference in the density of the sodium in the different scatterers, and subtracting it from the NaCl spectrum. The chlorine spectrum is also multiplied by a factor and subtracted from the CsCl spectrum and thus results in the cesium spectrum (Figure 10).

Figure 8 shows a sodium peak at 0.43 Mev which is also reported by several investigators (1, 3, 11). The other peaks are probably introduced through the subtraction process and therefore these are attributed to sodium.

The chlorine spectrum (Figure 9) shows a peak at 0.160 Mev which is possibly shifted because of subtraction of the valley in the sodium spectrum. Endt and Van der Leun (4) reported energy levels such that a gamma-ray transition in chlorine with energy of 0.163 Mev is possible. There are no other prominent peaks in this spectrum.

The cesium spectrum taken with the solid state detector (Figure 10) shows a rather complicated spectrum as compared with the spectrum obtained from the NaI crystal. No assignment is made in the case of the 0.136 Mev peak, but further investigation needs to be made since it does appear in both cesium spectra. Dawson (3) obtained a 0.135 Mev peak, but assigned it to iodine. However, no iodine was present when the Ge(Li) detector was used.

The 0.157 Mev peak is assigned to cesium and is in agreement with the gamma ray detected in both Ba^{133} decay (9, 12) and Coulomb excitation of cesium (5).

The valley at 0.160 Mev is an inverse peak due to the intense peak in chlorine and the series of peaks from 0.170 Mev to 0.22 Mev cannot be resolved and is probably the result of not being able to normalize the background.

The peak at 0.31 Mev is assigned to cesium. A level at 0.302 Mev has been reported by others (5, 9, 12).

There is evidence of higher energy gamma rays, but due to the low number of counts in this region, the statistical variation is too large to resolve the peaks. Further investigation is needed using the coincidence count between the gamma rays and the alpha particles. This would have the effect of reducing the high background count and would provide longer counting periods without the problem of overloading the multichannel analyzer. Also, the doubt introduced by the subtracting of the spectra would be eliminated.

This investigation has successfully shown that there are definitely higher energy gamma rays in cesium. With improved resolution the higher energy gamma rays could perhaps be resolved.

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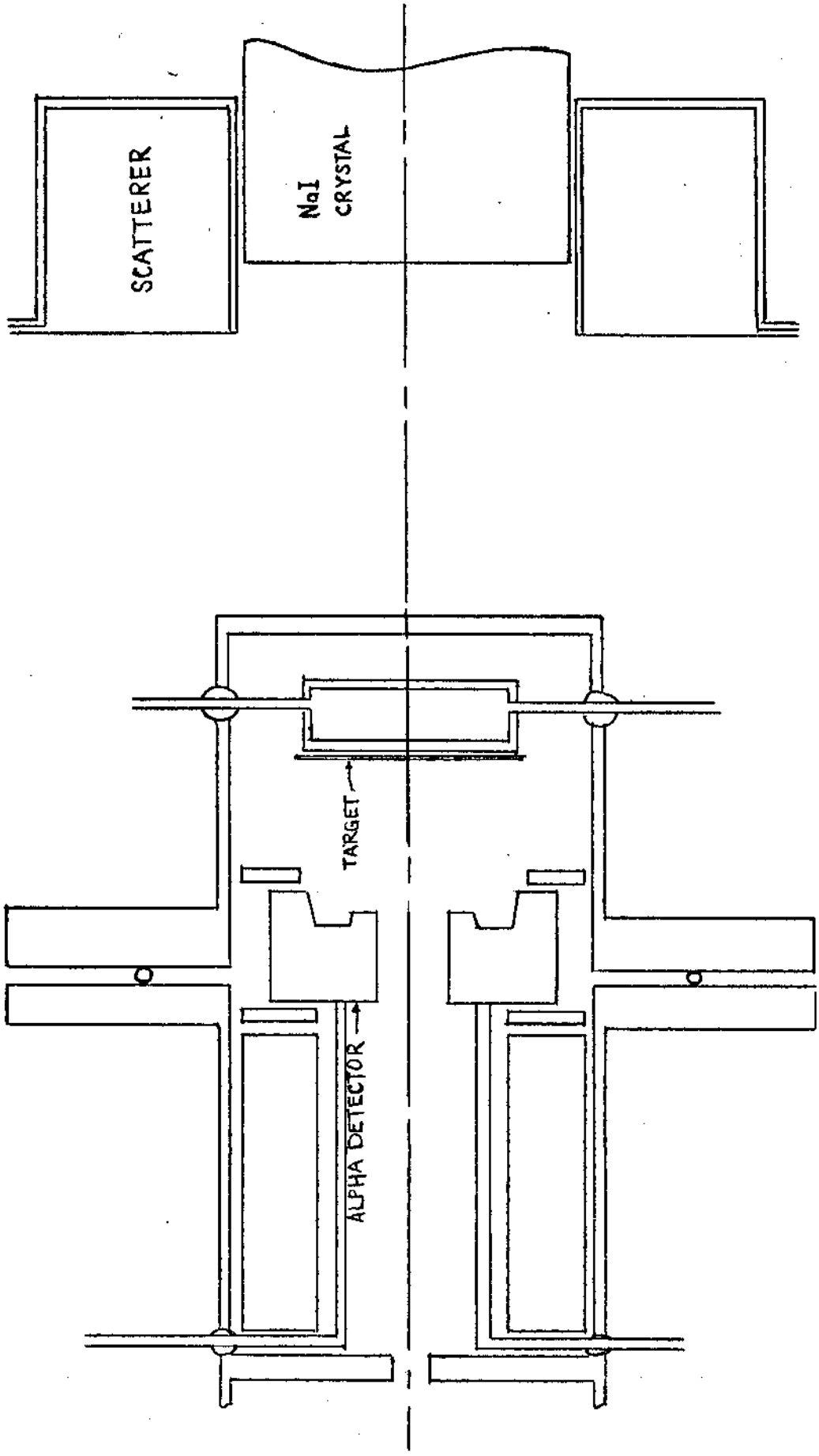

Figure 1--Arrangement of detectors and scatterer

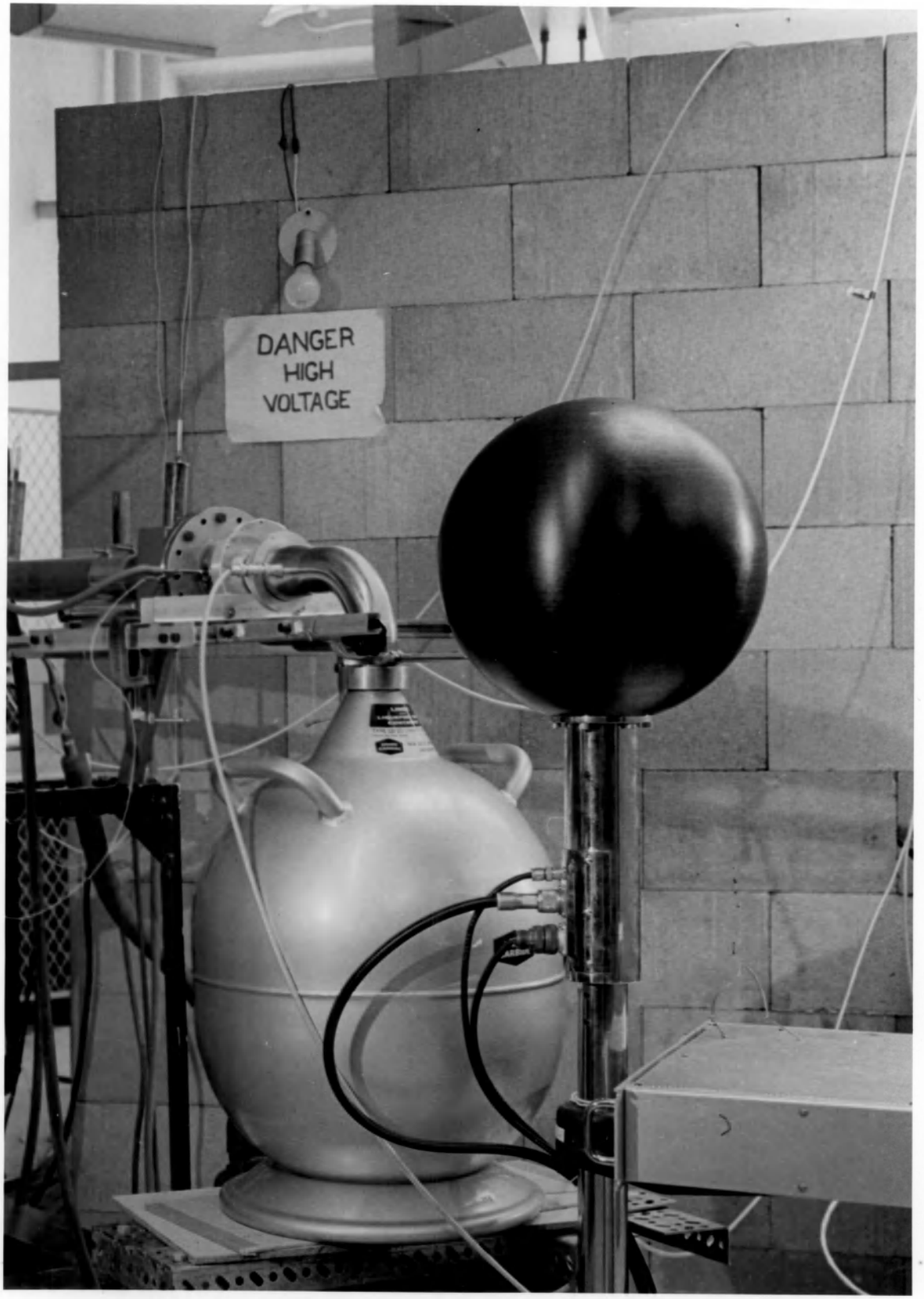

Figure 2--Gamma-ray detector and neutron detector

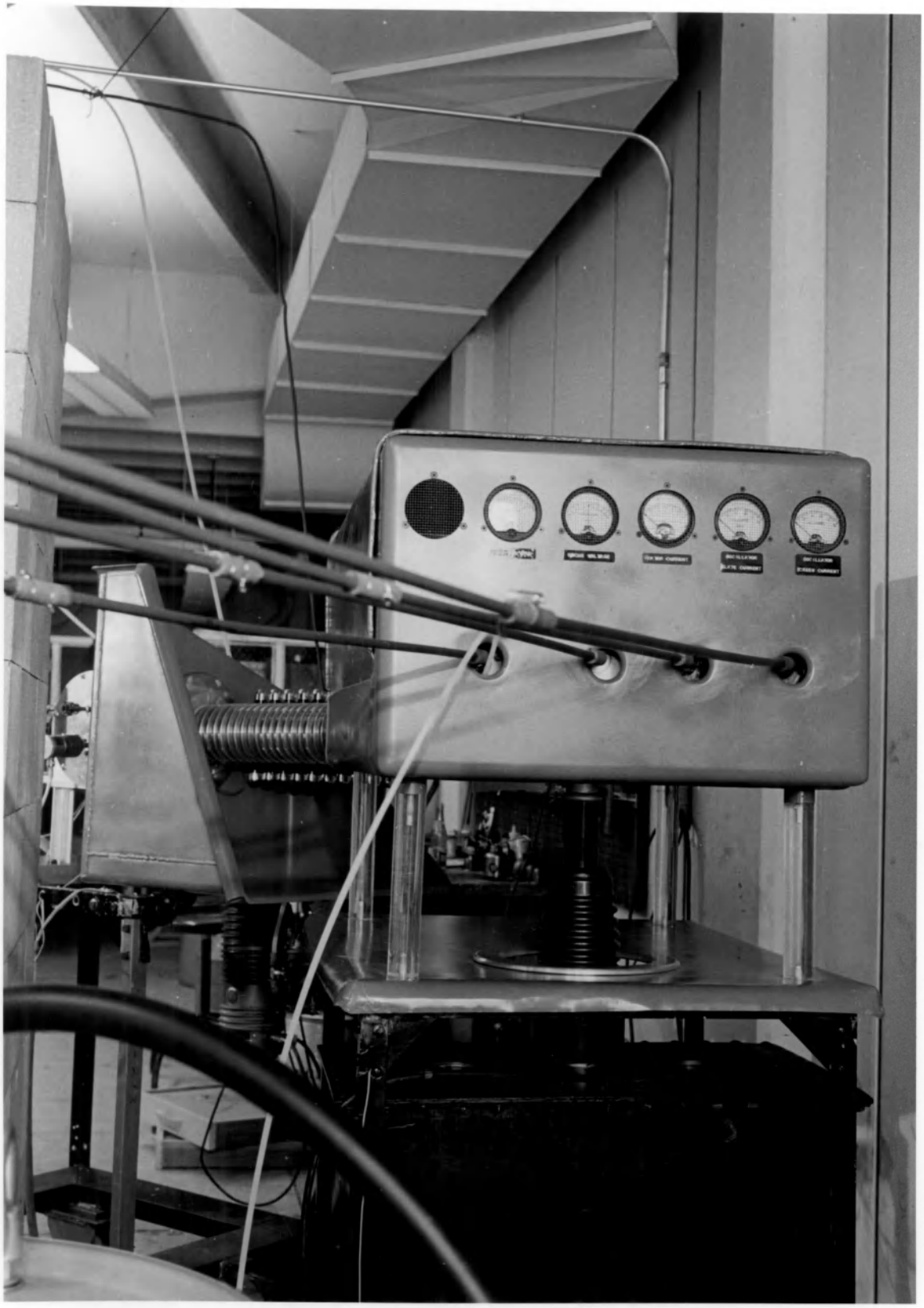

Figure 3--Beam-current controls

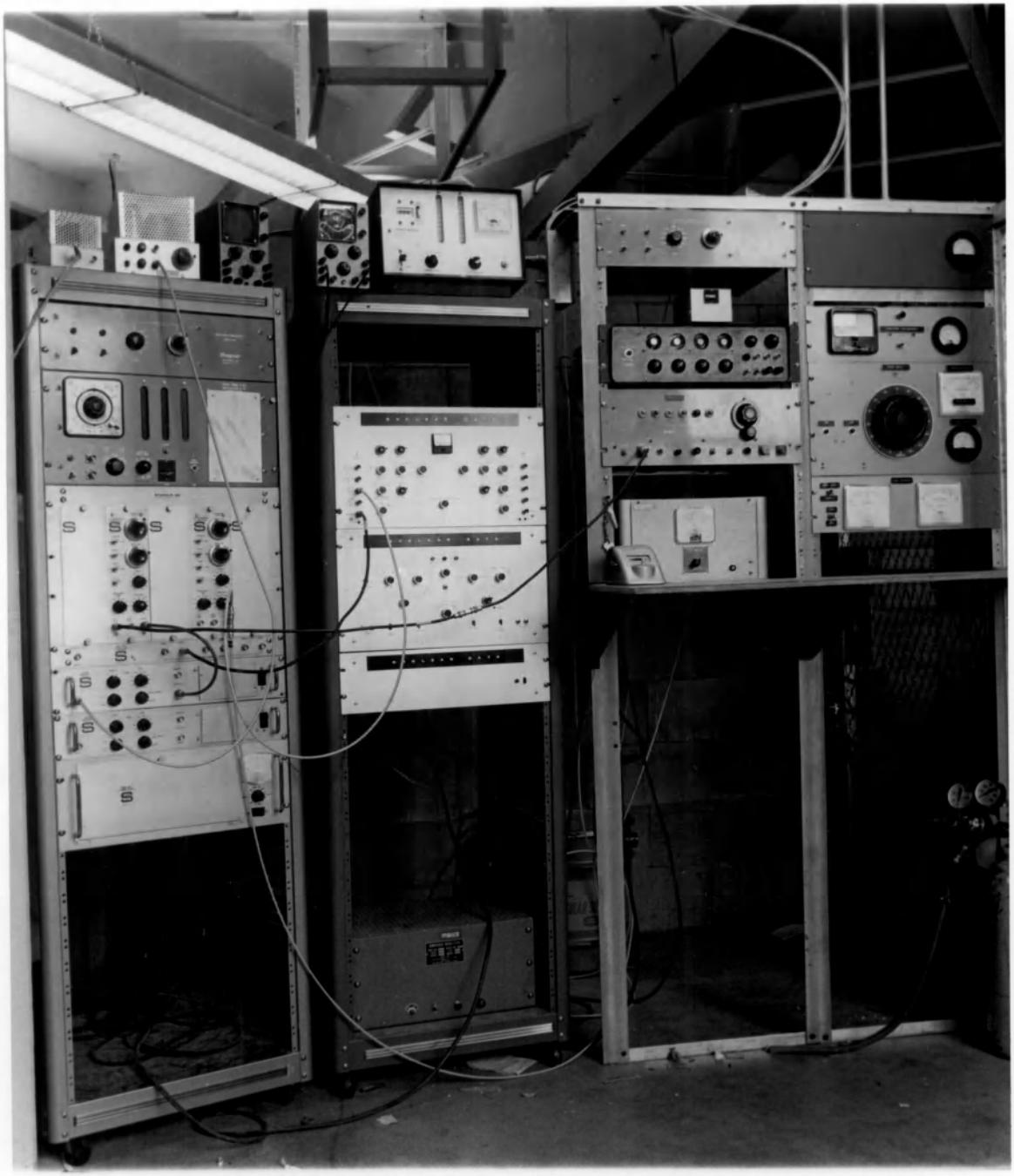

Figure 4--Instrument panel

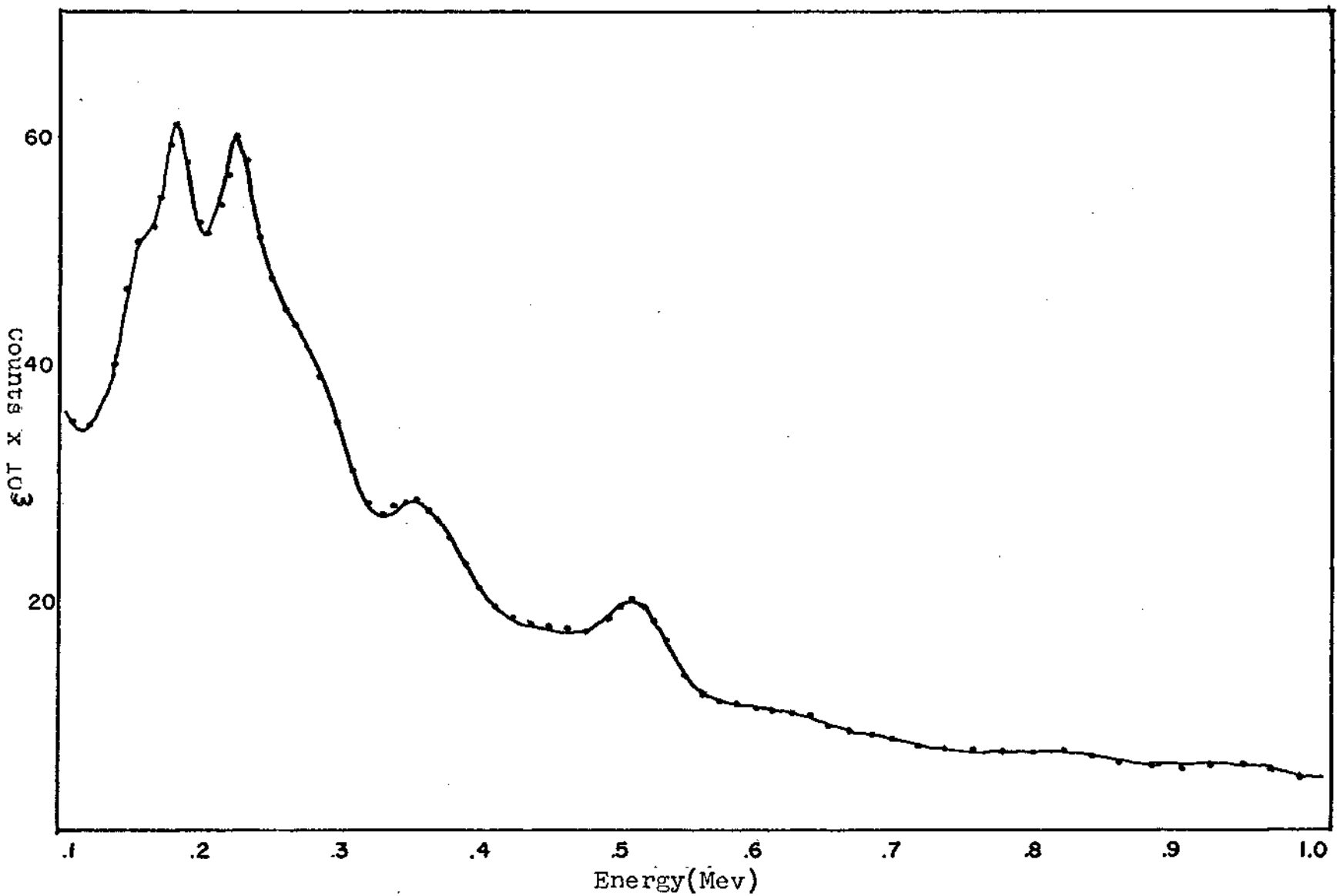

Figure 7--Background: NaI crystal

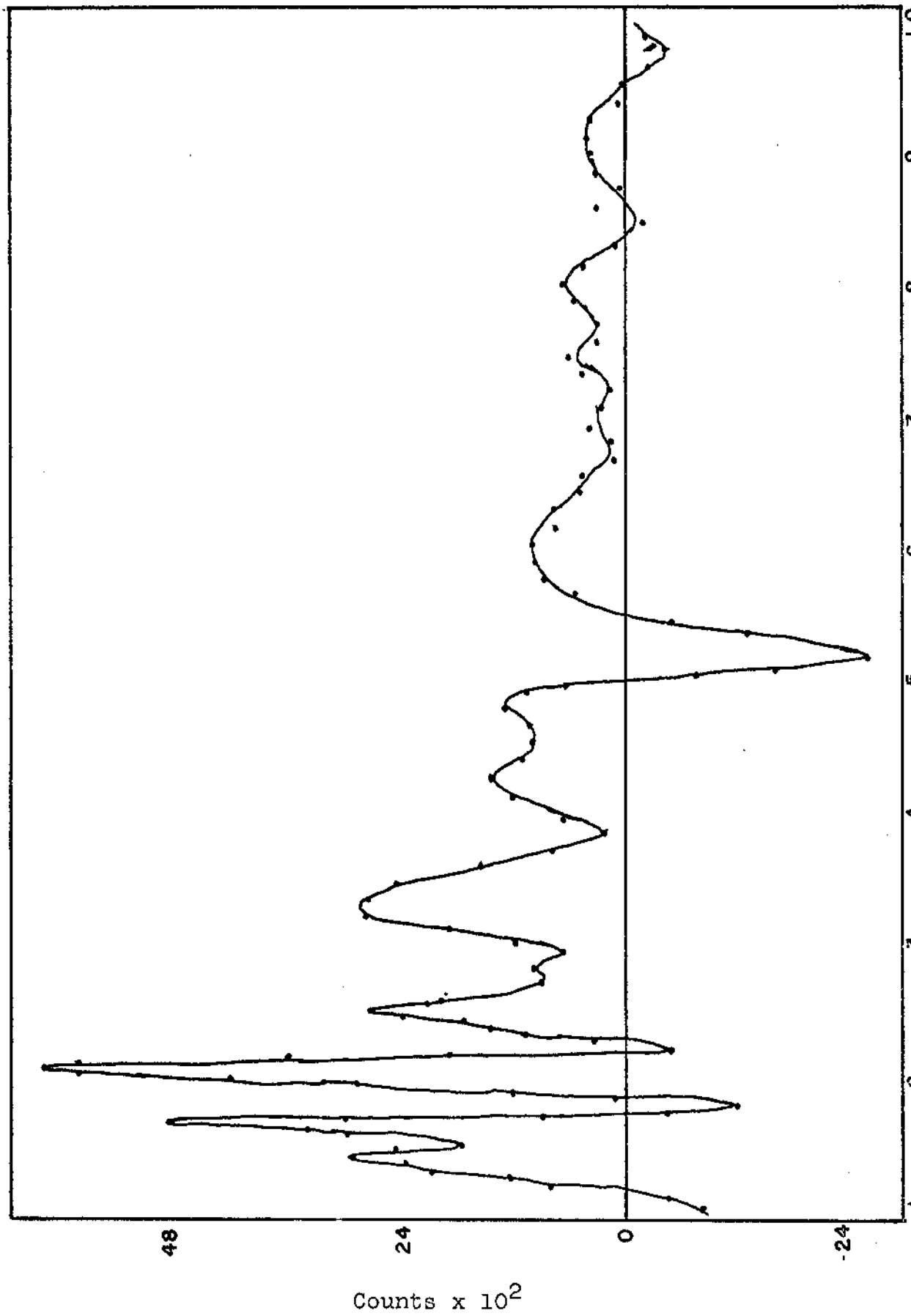

Figure 6--Cesium spectrum: NaI crystal

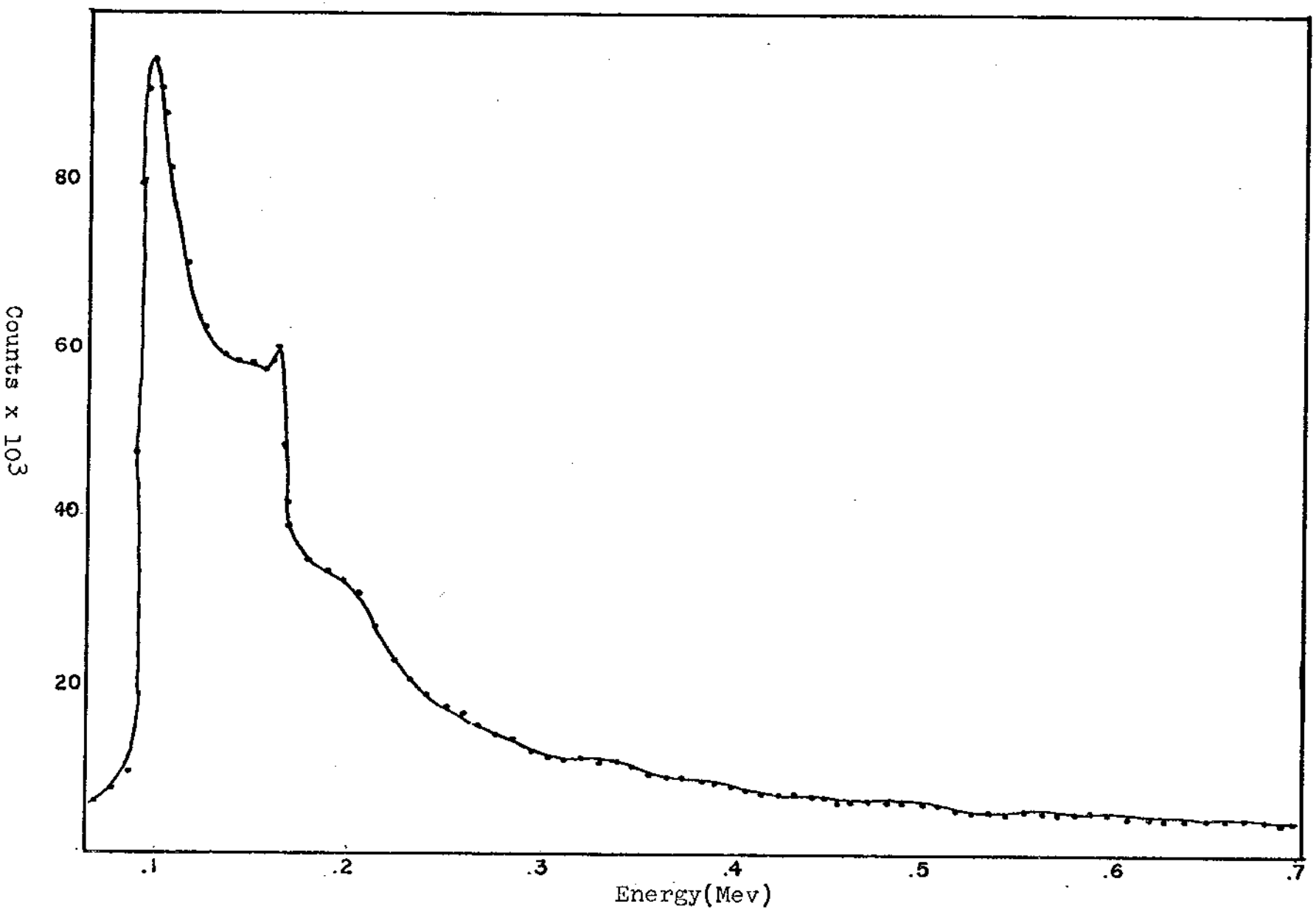

Figure 7--Background: Ge(Li) detector

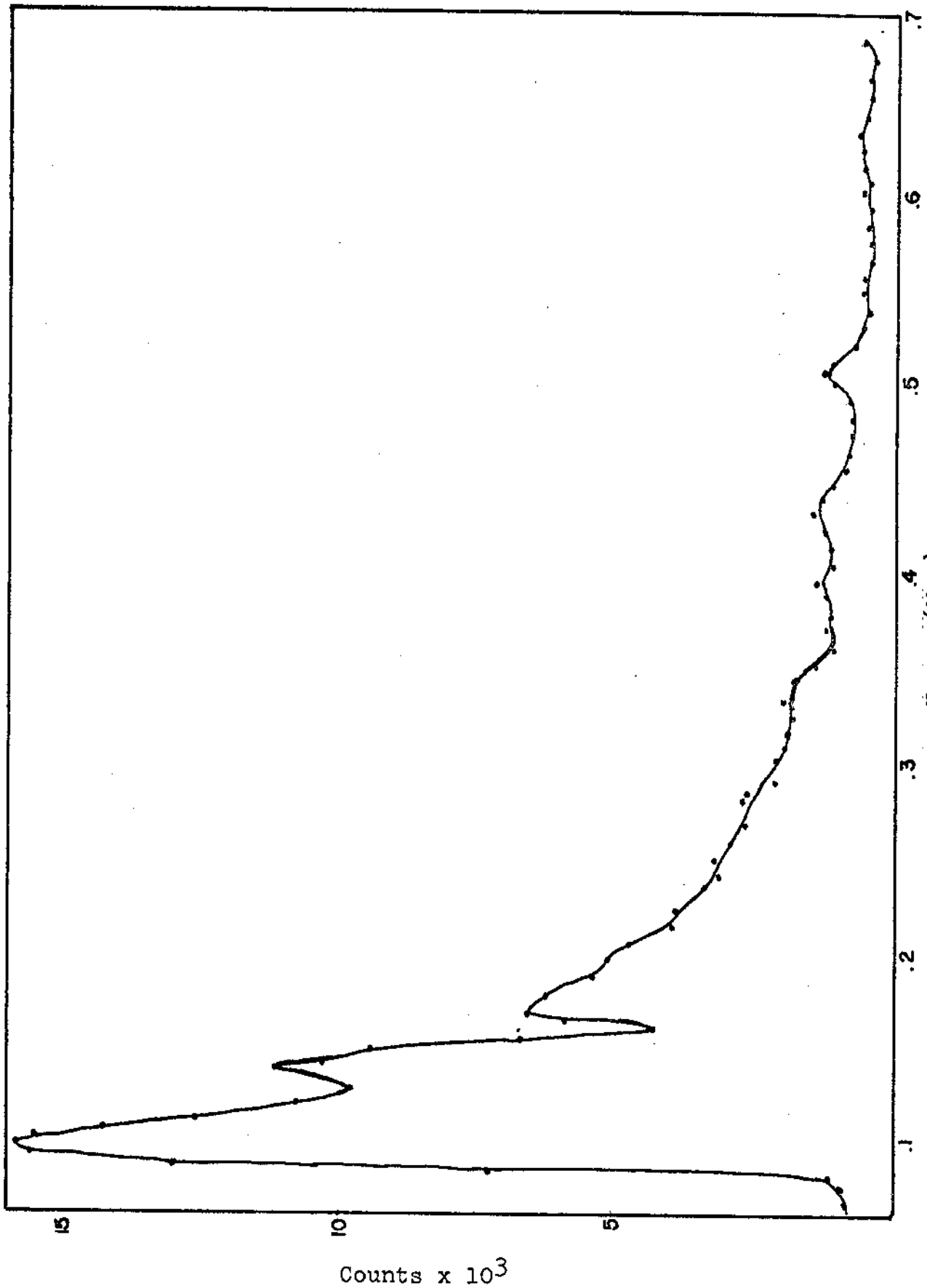

Figure 8--Sodium spectrum: Ge(Li) detector

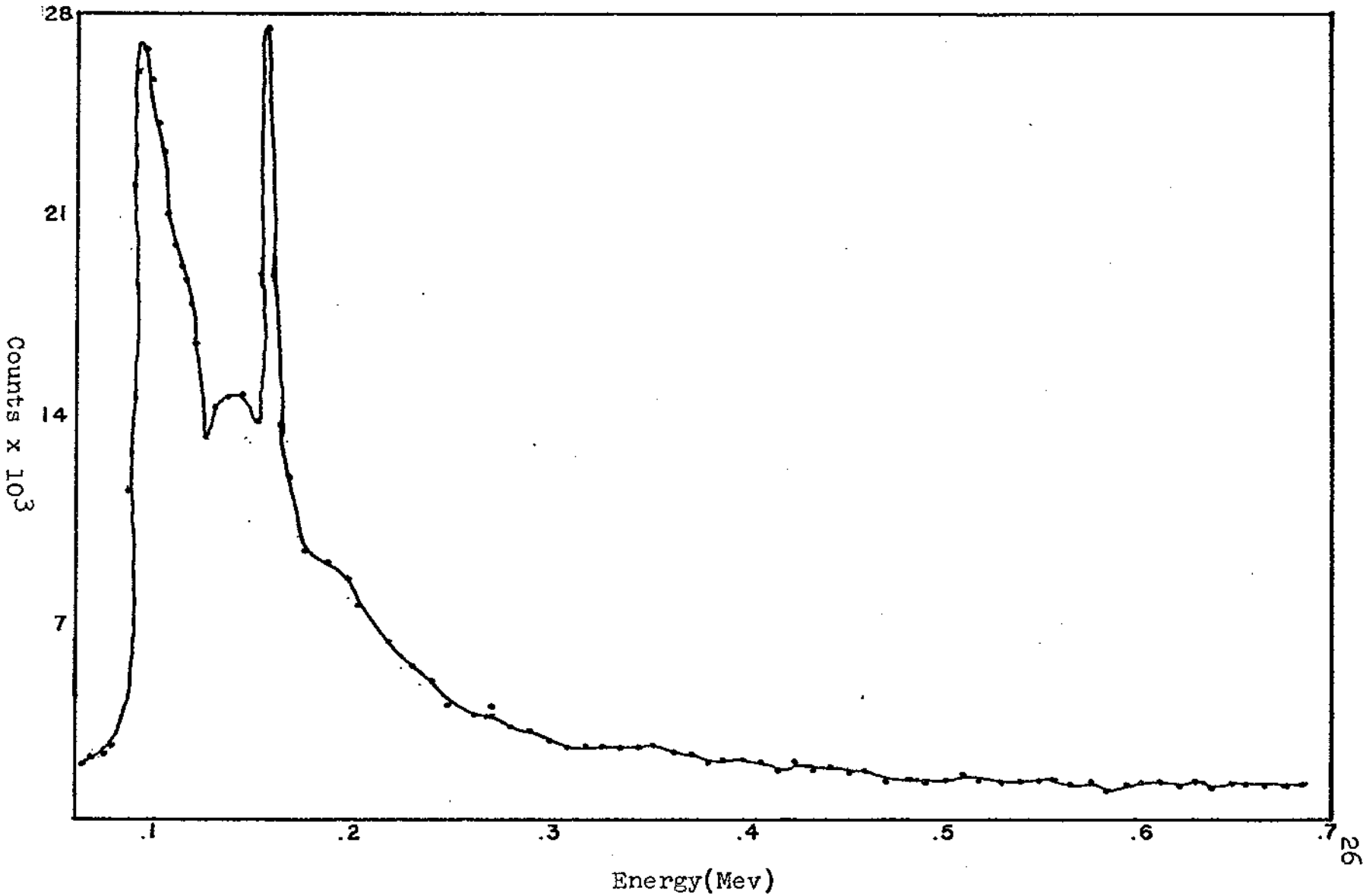

Figure 9--Chlorine spectrum: Ge(Li) detector

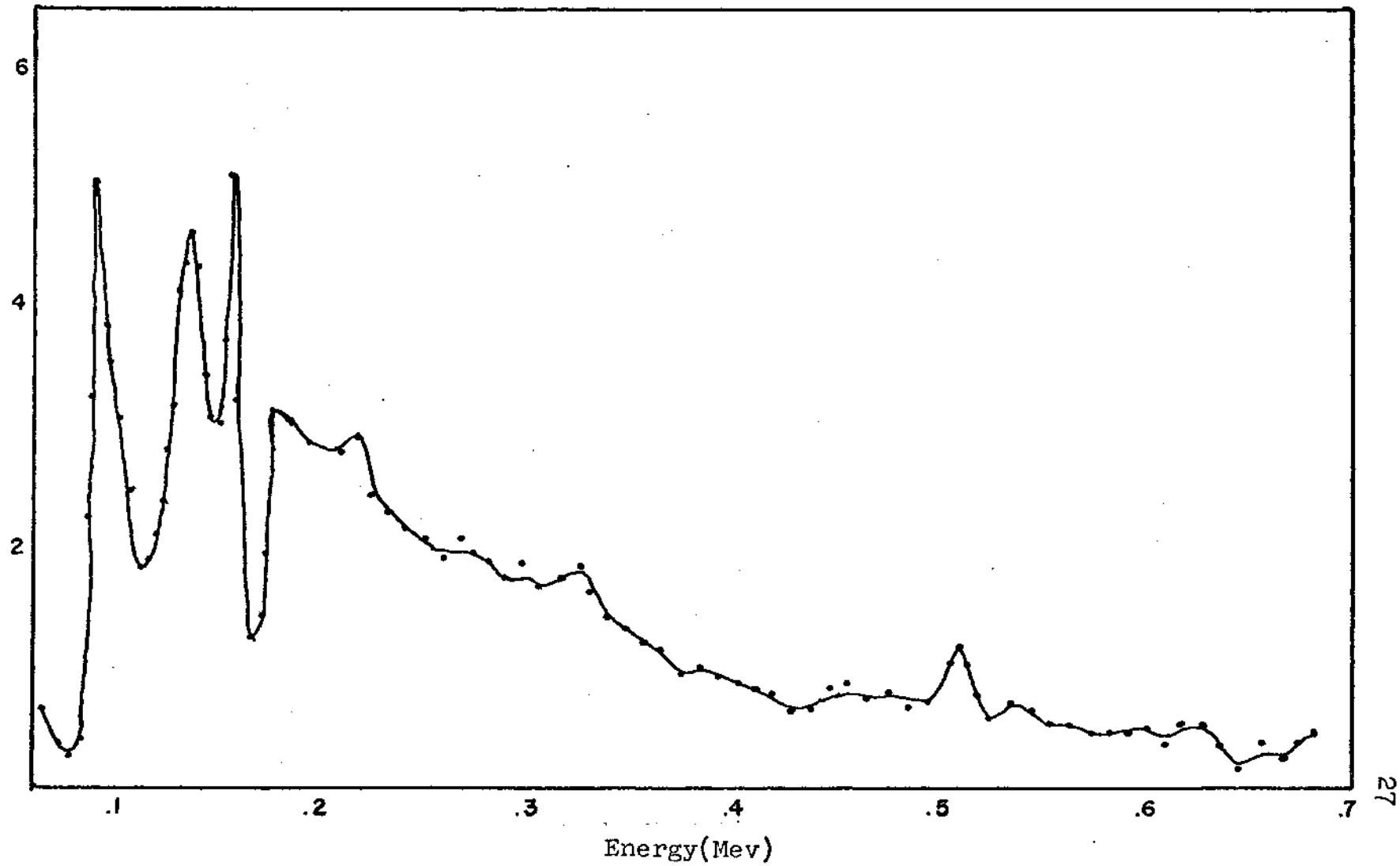

Figure 10--Cesium spectrum: Ge(Li) detector

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