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LITHIUM DRIFTED SEMICONDUCTOR DETECTORS IN NUCLEAR SPECTROSCOPY

by

G. BERTOLINI, F. CAPPELLANI, W. FUMAGALLI, M. HENUSET
and G. RESTELLI

1965

Joint Nuclear Research Center
Ispra Establishment — Italy

Chemistry Department
Nuclear Chemistry Service

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INTRODUCTION (°)

The construction and performances of lithium drifted semiconductor detectors as spectrometers, have been extensively described in literature (1)

The intrinsic high resolution of these detectors together with the development of low noise preamplifiers, allow a very good resolution, either in beta either in gamma spectroscopy, respectively by Si and Ge detectors.

The results obtained in the study of alpha particle ionization in gases on the Fano factor ($F \leq 0{,}08$) (2) and those obtained in electron spectroscopy by surface barrier detectors (3) (fwhm =

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(1) - F.S. GOULDING : I.E.E.E. NS-11 n° 3 - (1964) - 177

(2) - VOROBYOV : private communication

(3) - H.J. LANGMANN and O. MEYER : Nucl. Instr.&Meth. 30 (1964) 135.

(°) Manuscript received on August 31, 1965

= 2.9 KeV for 624 KeV electrons with 2.7 KeV for electronics) seem to indicate that the ultimate limit in resolution also in semiconductor detectors is not yet achieved and is practically conditioned by the construction technology and the electronic noise.

In this paper we present a short description of the techniques used in this laboratory in the construction and some examples of the utilization of these detectors in electron and gamma spectroscopy.

CONSTRUCTION:

The procedure followed in the construction of the detectors is based on the results obtained by Pell (4) on lithium drifting in p - n junctions.

Li diffuses interstitially in Si and Ge, with an higher mobility in the second one.

Nevertheless while silicon diodes can be drifted at temperature of the order of 150°C or more depending on the resistivity of the starting material, germanium diodes have been drifted at temperatures of the order of 60° - 70°C at maximum.

This limit is imposed by the higher thermally generated current due to the lower energy gap (Ge : 0,63 ev - Si : 1,04 ev).

P-type silicon crystals ranging in resistivity from 100 to 1500 Ωcm and p-type Germanium of resistivity 5-10 Ωcm, have been used.

In the case of Ge, dislocation density in the starting material is a very critical point because dislocations in the crystal act as nucleation points for Lithium precipitation : an EPD at least below 2000 cm^{-2} is necessary.

Lithium metal is evaporated in vacuum on one face of the etched crystal and then diffused in argon flow at temperatures of respectively 400°C for Si and 350°C for Ge.

Electroless Ni plating provides ohmic contacts.

The drift is performed in air using an automatic system of control of the drift temperature and of the power dissipated into the diode (5).

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(4) - E.M. PELL : J. Appl. Phys. : 31 (1960) 291.

(5) - G. DEARNALEY, G.C. LEWIS : AERE R-4335 (1963).

Drifted depths are determined by capacitance measurements and stain techniques. In the case of Silicon, in order to get windowless type detectors for electron and low energy gamma spectroscopy, the diode is drifted to the opposite side and then a surface barrier is produced on this side by etching and subsequent gold evaporation (n +-i-p+) (5). Sensitive depths of the order of 8 mm in Silicon and 7 mm in Germanium have been obtained with useful areas up to 3 cm^2 .

The storage of Si detectors does not present problems: although not necessary the continuous application of a 50-100 volt bias to the diodes improves the lithium compensation. For Ge detectors the only efficient storage we have found, is in vacuum at liquid nitrogen temperature: in these conditions detectors have been operated for months without appreciable worsening of the characteristics.

SILICON DETECTOR:

The application of this detector in nuclear spectroscopy seems to fit particularly measurements of beta spectra and internal conversion electrons.

Its utilization as gamma spectrometer is drastically limited to low energy gammas and X-rays due to the low absorption efficiency and atomic number of Silicon.

Sometimes the use of silicon can be preferred to germanium when it is of interest to evidenciate a peak respect to a near one of higher energy and intensity. A typical gamma spectrum is shown in fig. 1. In the application to electron and beta spectroscopy, the detectors are operated at about 255°K using a Peltier effect device. The resolutions obtained are of the order of 7 KeV for conversion electrons of Cd 109 88 KeV and Cs 137 661 KeV gammas, for a 50 mm^2 x 2 mm detector. (6)

Resolutions of 7 KeV for the conversion electrons of the 661 KeV gamma of Cs 137 for a 250 mm^2 x 3 mm detector have been obtained by cooling at 190° K.

In a previous paper (7) we have pointed out, referring to surface barrier detectors, the importance of the knowledge of the backscat-

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(6) - G. BERTOLINI, F. CAPPELLANI, G. RESTELLI: Nucl. Inst. and Meth. 32 (1965) 86.

(7) - G. BERTOLINI, F. CAPPELLANI, R. FANTECHI, G. RESTELLI: Nucl. Inst. and Meth. 27 (1964) 281.

tering tail associated to the electron peaks of different energies, to give a correct interpretation of the continuous beta spectra.

The knowledge of the backscattering is obviously required also to make evaluations of internal conversion coefficients.

In the study of radioactivity of U 232 (8) in the determination of $\frac{L}{M}$ conversion ratios for the 58 and 128 KeV transitions (fig. 2) it has been observed that this ratio would be affected by an error of about 15% for the 58 KeV conversion electrons and of the order of 5% for the 128 KeV conversion electrons, if the backscattering is not taken into account.

The error becomes much higher, of course, if the evaluation is made for peaks quite far in energy; as for instance for K/L ratios.

GERMANIUM DETECTOR:

In our laboratory at this moment, germanium detectors find their applications in activation analysis and in heavy elements studies.

A problem treated in activation analysis was the determination of hafnium in hafnium depleted zirconium oxide; this is of interest due the importance of the problem in nuclear technology and also on account of the difficulty to perform a chemical separation between Hf and Zr. By a scintillation spectrometer, namely a NaI (Tl) 3" x x 3" crystal, an evaluation is impossible for Hf content below 100 ppm (9).

Fig. 3 - 4 and 5 show gamma spectra taken by a Ge detector of pure HfO2, of natural zirconium containing 2% of Hf and finally of a depleted sample with unknown Hf content.

The determination can be performed using either the 130 KeV or the 480 KeV gamma line of Hf 181; a content of about 100 ppm has been obtained with good agreement between the values (93 and 103 ppm respectively) resulting from the two peaks. The estimated sensitivity of the method is 10 ppm.

In heavy elements the presence of a certain number of gamma and

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(8) - G. BERTOLINI, F. CAPPELLANI, G. RESTELLI, H.L. SCHERFF: Nuclear Physics to be published.

(9) - Y. KAMEMOTO, S. YAMAGISHI: Nippon Kagaku Zasshi 84 (1963) 270.

Xrays peaks of near energy inhibits a good determination of energies and relative intensities of the radiations.

Fig. 6 shows a gamma spectrum from a source of Pu 240 of the following isotopic composition:

Pu 239 : 2,96 %
Pu 240 : 96,8 %
Pu 241 : 0,2 %
Pu 242 : 0,03 %

From the spectrum the relative intensities of the gamma transitions with respect to the total alpha transitions have been determined. Table I shows the data obtained compared with those in ref. 10.

The total conversion coefficients for the 45 and 104 KeV transitions are reported together with the theoretical values calculated for E 2 transitions.

The conversion coefficients for the 163 and 210 KeV gamma are not given due to the strong dependence on the alpha branching (11) and decay scheme assumed.

T A B L E I

GAMMA Energy	Gamma intensities % of decay	Ref. 10	Total conversion coefficients experimental	(E2) theoretical
45 KeV	$4,5 \times 10^{-2}$	$3,6 \times 10^{-2}$	540	613
104 KeV	$7,1 \times 10^{-3}$	$9,1 \times 10^{-3}$	11,8	11,35
163 KeV	$4,7^{+0,5}_{-} \times 10^{-4}$	$5,1 \times 10^{-4}$		
210 KeV	$4,2^{+0,6}_{-} \times 10^{-4}$	$4,8 \times 10^{-4}$		
X KL	$5,3 \times 10^{-4}$			
X KM-N	$1,43 \times 10^{-3}$			

Acknowledgments: The authors are indebted to R. BENOIT for designing the low noise preamplifiers, to the activation analysis group for the Hf determination and to A. OSTIDICH for preparation of Plutonium sources.

(10) - J.E. CLINE: IDO 16695 (1961) 43

(11) - E.F. TRET'YAKOV, L.N. KONDRAT'EV, G.I. KHLEBNIKOV and L.L. GOL'DIN, JETP 9 (1959) 250.

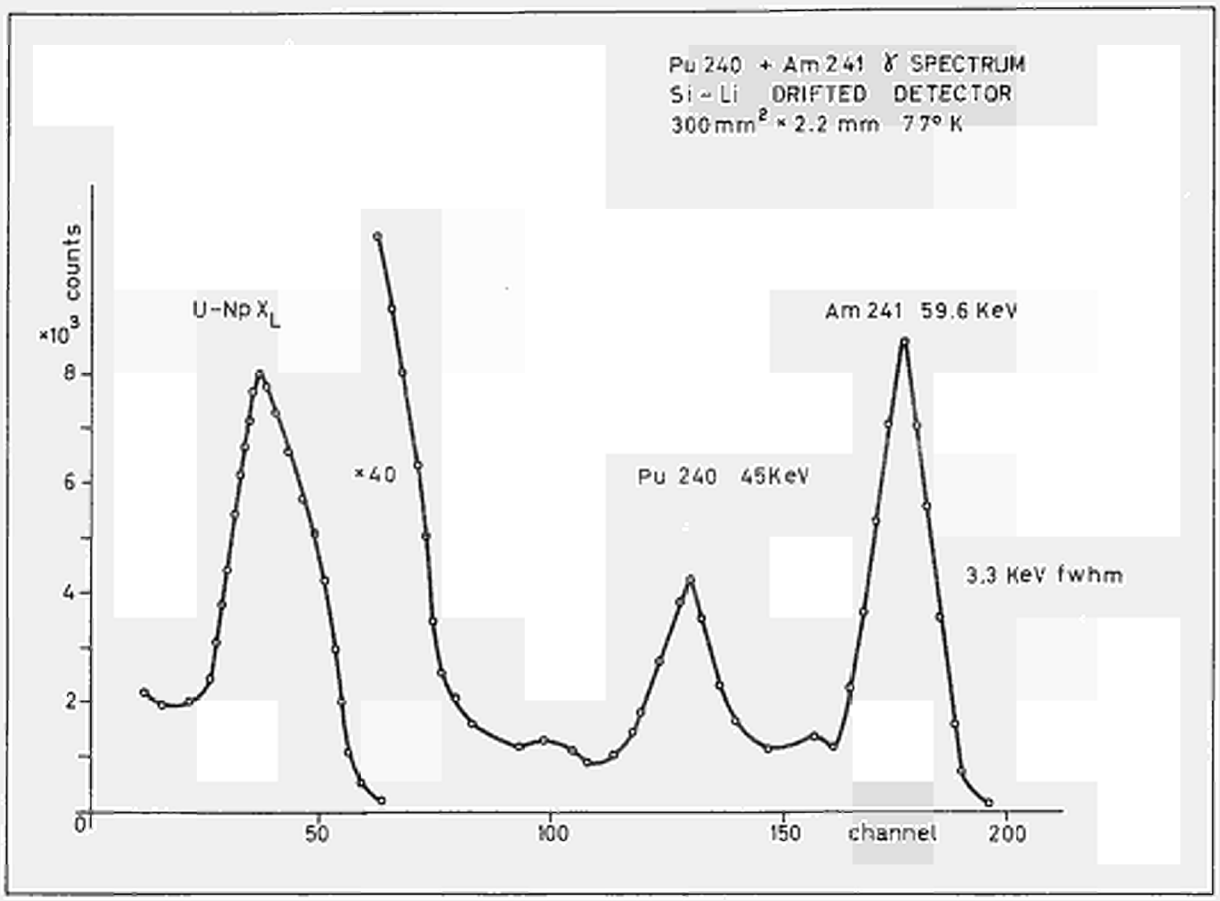

Pu 240 + Am 241 γ SPECTRUM
Si - Li DRIFTED DETECTOR
300 mm² × 2.2 mm 77° K
×10³ counts
U-Np X_L
×40
Pu 240 45KeV
Am 241 59.6 KeV
3.3 KeV fwhm
channel

Fig.1

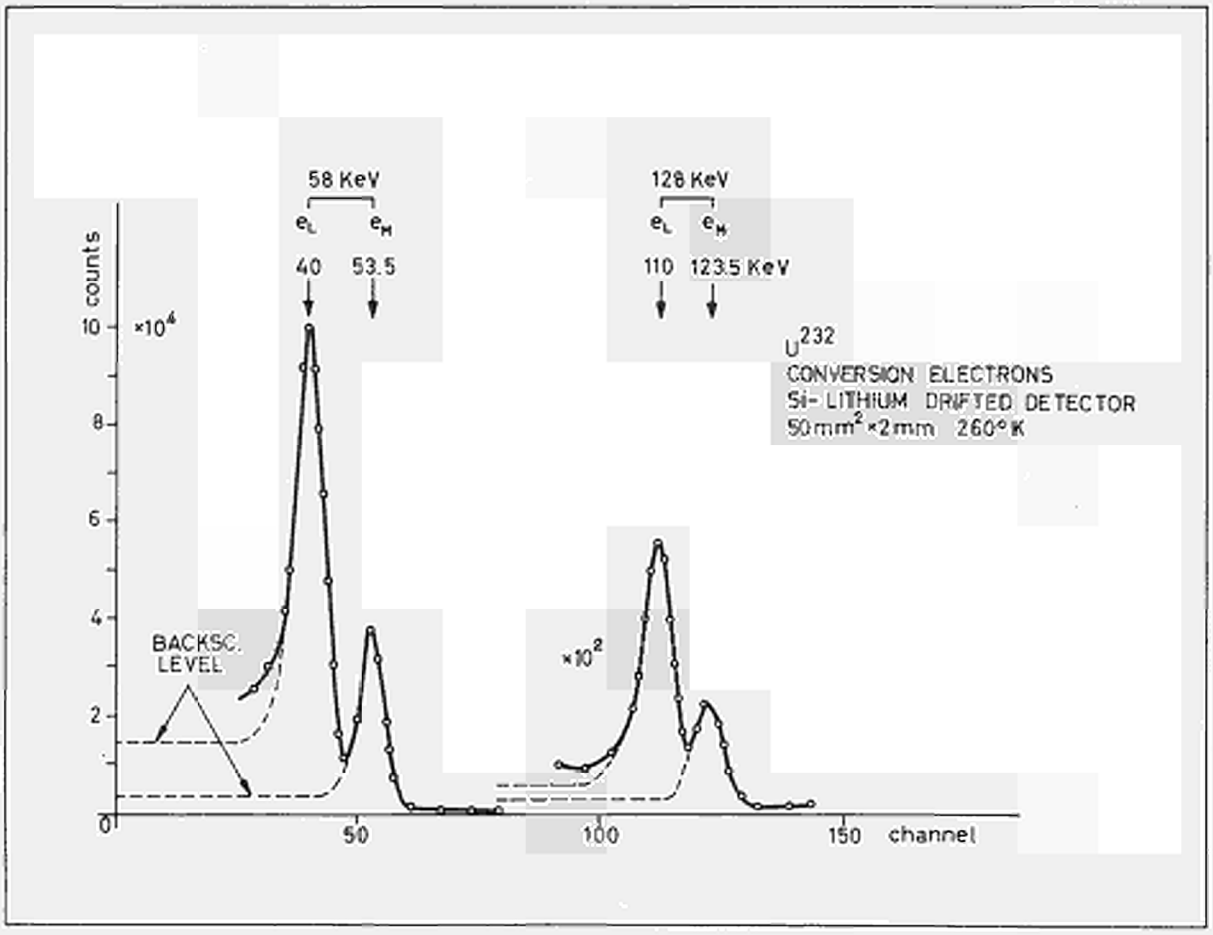

58 KeV
e_L e_H
40 53.5
128 KeV
e_L e_H
110 123.5 KeV
counts
×10⁴
×10²
BACKSC. LEVEL
U²³²
CONVERSION ELECTRONS
Si-LITHIUM DRIFTED DETECTOR
50 mm² × 2 mm 260° K
channel

Fig.2

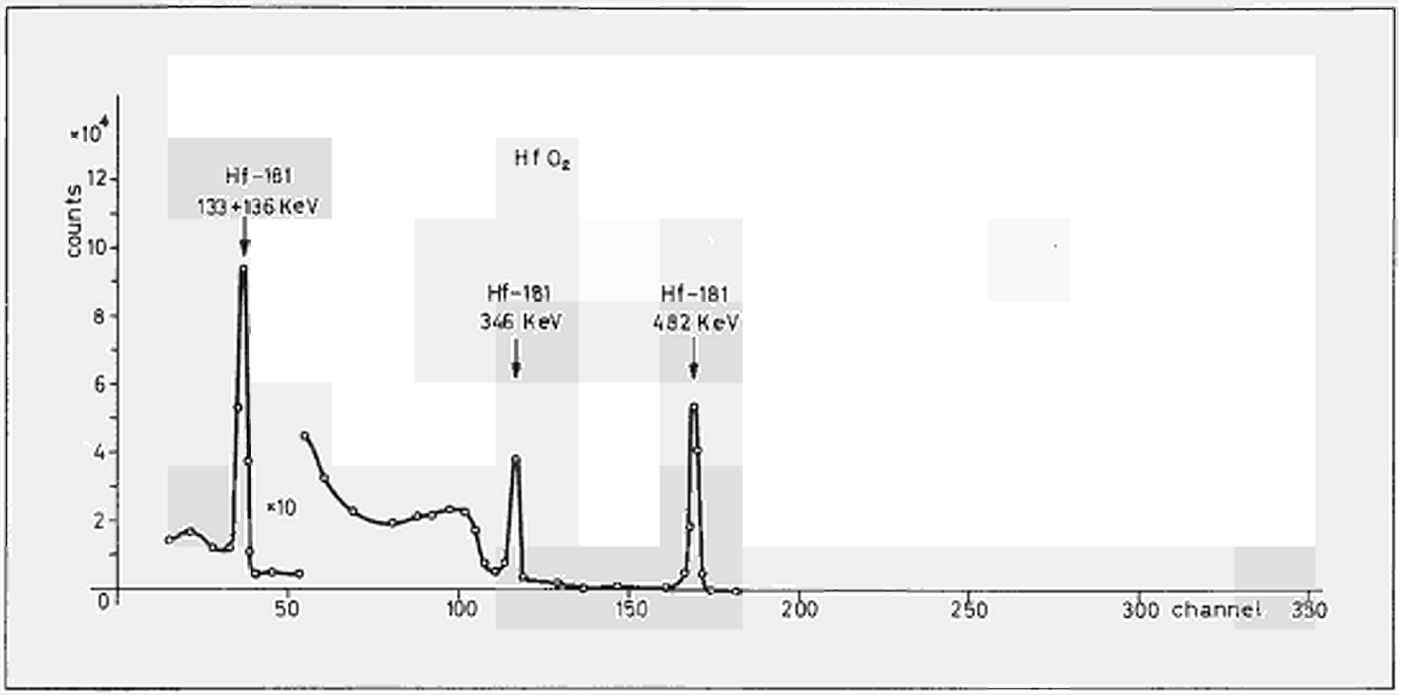

counts
×10⁴
12
10
8
6
4
2
0
Hf-181
133+136 KeV
Hf O₂
Hf-181
346 KeV
Hf-181
482 KeV
×10
50
100
150
200
250
300 channel
350

Fig.3

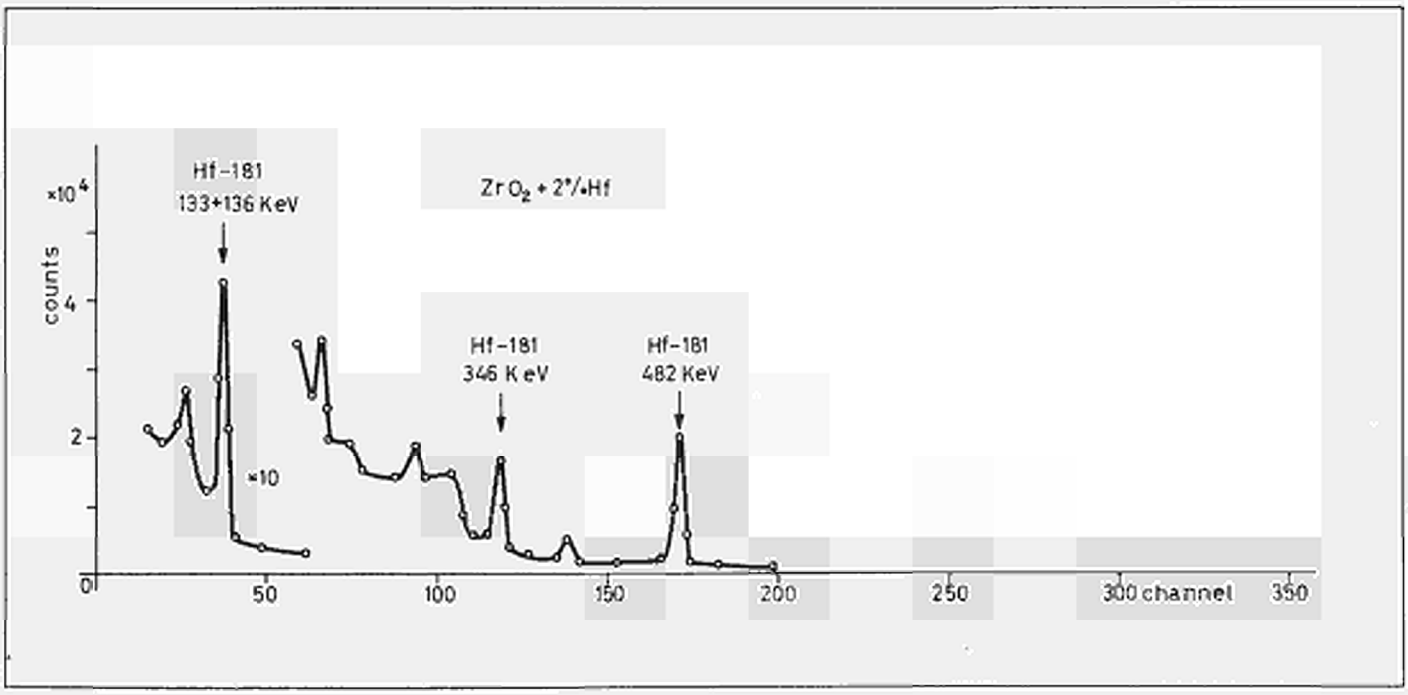

counts
×10⁴
4
2
0
Hf-181
133+136 KeV
Zr O₂ + 2% Hf
Hf-181
346 KeV
Hf-181
482 KeV
×10
50
100
150
200
250
300 channel
350

Fig.4

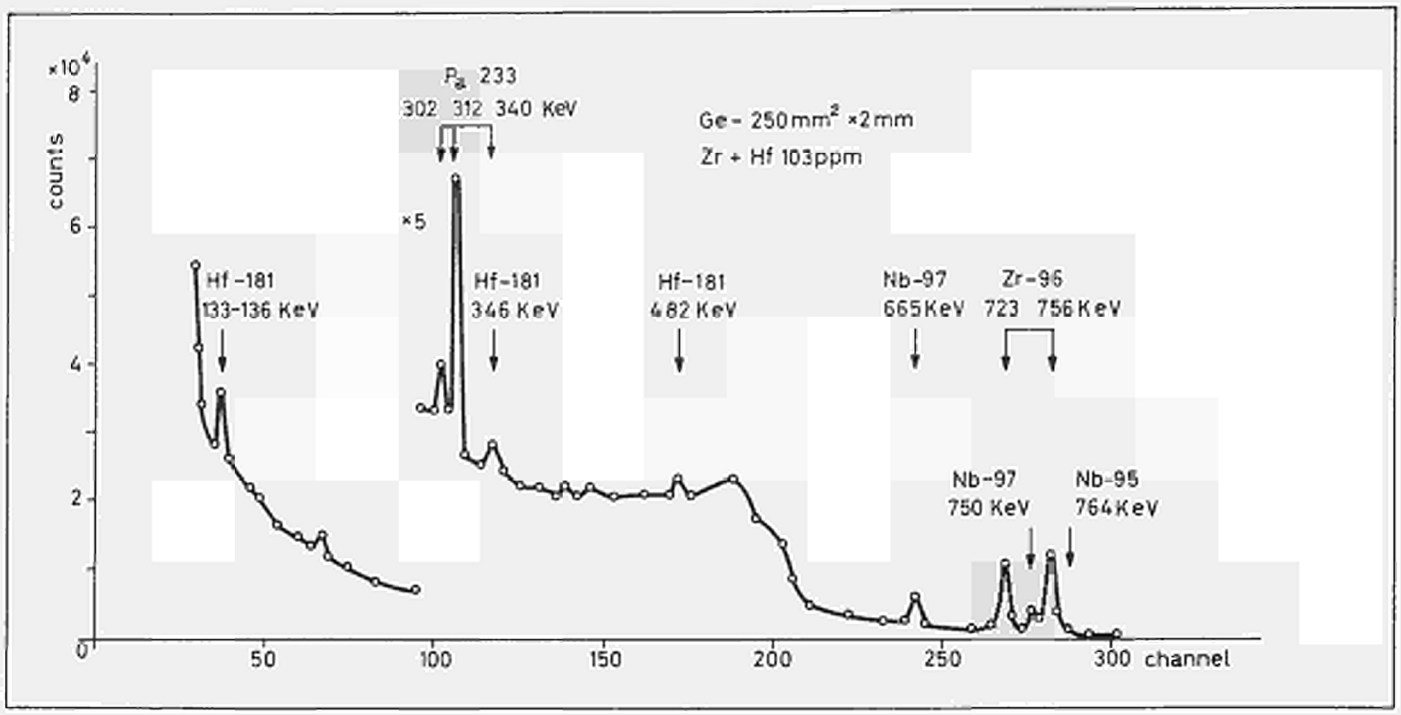

×10⁴
counts
Pa 233
302 312 340 KeV
Ge - 250mm² ×2mm
Zr + Hf 103ppm
×5
Hf-181
133-136 KeV
Hf-181
346 KeV
Hf-181
482 KeV
Nb-97
665KeV
Zr-96
723 756 KeV
Nb-97
750 KeV
Nb-95
764KeV
channel

Fig.5

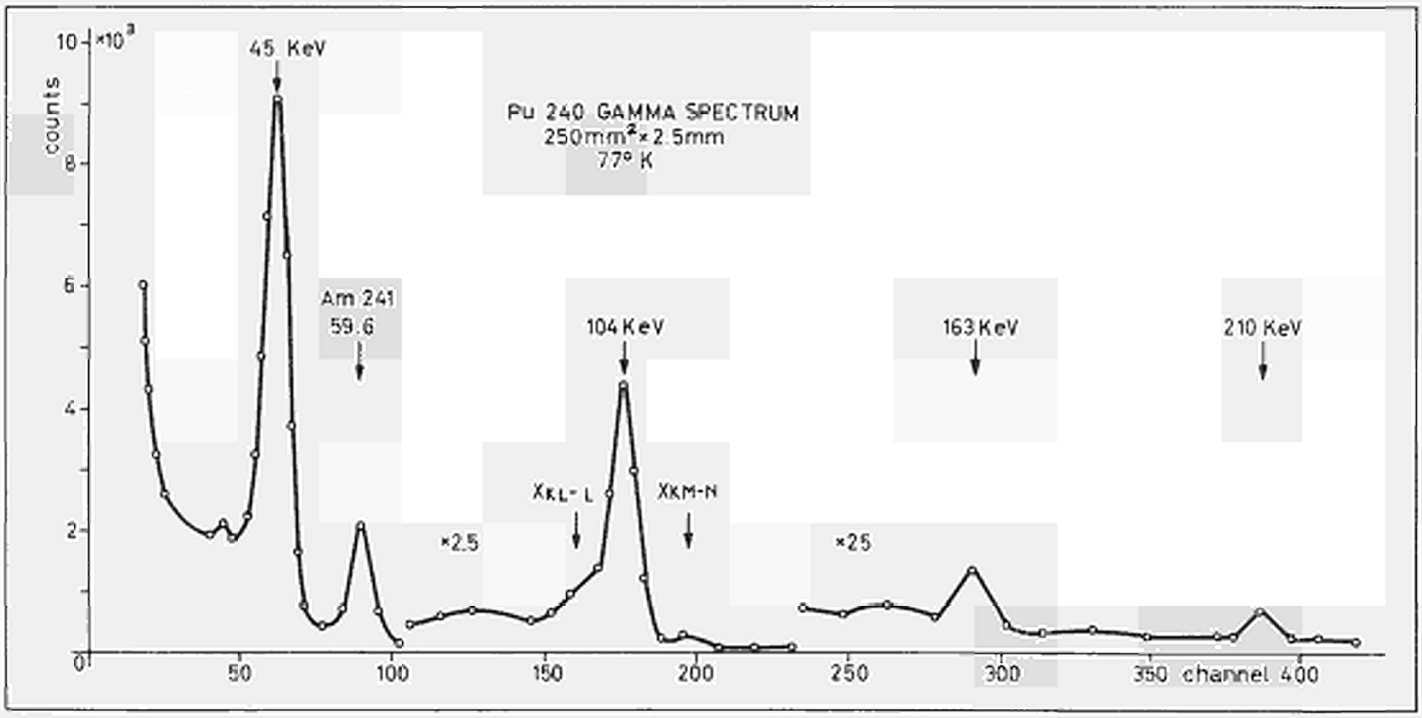
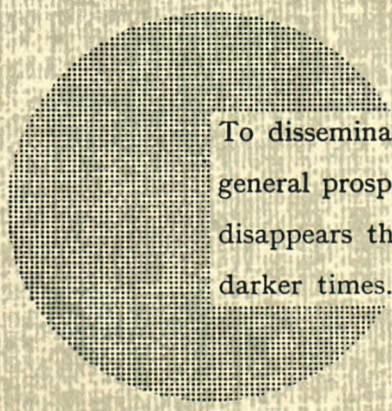

×10³
counts
45 KeV
Pu 240 GAMMA SPECTRUM
250mm²×2.5mm
77° K
Am 241
59.6
104 KeV
163 KeV
210 KeV
XKL-L
XKM-N
×2.5
×25
channel

Fig.6



To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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