Turk J Phy
25 (2001) , 97 – 107.

Beta Spectrometers with Surface Barrier Detector and Plastic Scintillator: Applications to ^{90}Sr,^{204}Tl,^{210}Pb and ^{14}C.*

Cüneyt ÇELİKTAŞ

Ege University, Science Faculty, Physics Department,
35100 Bornova, İzmir - TURKEY

Received 04.05.2000

Abstract

In this work, a comparison of responses between a spectrometer using Si Surface Barrier Detector (Si SBD) and a spectrometer using Plastic Scintillator (PS) is given. Experimental pulse height spectra of beta particles from ^{90}Sr,^{204}Tl,^{210}Pb and ^{14}C pure beta sources has been obtained separately. By comparing obtained spectra, the priority of obtaining the beta spectra among them is discussed.

This work is related to the spectral response of beta spectrometers to pure beta sources.

1. Introduction

Absorption, scattering and reactions of beta particles with target material, and the investigation of energy losses within them are only possible by obtaining their pure spectra. For this reason, the development of beta spectrometers giving true and reliable beta spectra, and control of the results acquired from these spectrometers are of main practical importance. Since the range of penetration in matter varies due to multi-scattering, the energy portion lost in detector material varies statistically. This change depends effects such as excitation, ionization, nuclear interactions and bremsstrahlung of the particles incident on a detector, as well as and radiation damage. Incident angels of beta particles at detector surface are also important due to scattering and backscattering from the detector surface.

Research with Geiger-Müller [1], NE 102A plastic scintillator [2,3], Si SBD [4,5,6,7,8,9,10],

*This work was supported by Ege University, Science-Technology Research and Application Center.

n-type Si detector [11], and Si SBD and PS [12,13] are among some of the investigations that have been performed with beta spectrometers.

PS is the most widely used organic detector type in nuclear and particle physics. Interesting studies in the development and use of PS to measure particle energy are given in [3,14,15,16,2,17,18,19,20].

PS has approximately 2-3 ns decay constant and high light output, with the light pulse having temporal form

$$N(t) = N_0 f(\sigma, t) \exp(-t/\tau), \tag{1}$$

where N(t) is the photon emission rate at time t, N_0 is the total number of photons emitted, f(σ,t) is a Gaussian with a standard deviation σ, and τ is the decay constant [21].

The energy response of scintillators to beta rays [20] and to monoenergetic electrons has been studied by Titus [19]. Energy resolution R for incident electron with E_0(MeV) energy is given approximately [13] by

$$R = \frac{0.15}{\sqrt{E_0}}. \tag{2}$$

The types and the characteristics of PSs has been investigated in Akimovs work [18].

A charge and energy sensitive semiconductor detector such as Si SBD is very advantageous in detecting charged particles and determining their energies. These detectors are widely used, especially in alpha and beta spectroscopy [4,8,10]. The response of Si detectors to electrons has been investigated by some authors [22,23,24]. Stored energy in the detector depends on the incident particle energy [9].

Another characteristic of SBDs which should be taken into consideration is their sensitivity to light, due to their thin entrance windows which are optically transparent wherein photons can reach the active volume from the surface. Since the energy of visible light (2-4 eV) is larger than the energy band gap of Si SBD, artificial pulses may occur in the detector volume. Therefore, the detector must be put in a vacuum chamber isolated from light [25].

PSs are sensitive to light. Stray light leads to production of extra pulses and thus an increase in background. Therefore, data acquisition using this type of detector must be conducted in an environment isolated from light.

2. Materials and Methods

The schematic diagrams of the beta spectrometers used in this work are shown in Figures 1a and 1b. In order not to affect the results while the beta spectra is being acquired, it is important to use the same devices (e.g. BIN, spectroscopy amplifier) in both spectrometers. In addition, a minimum of electronics should be used to obtain cleanest spectra.

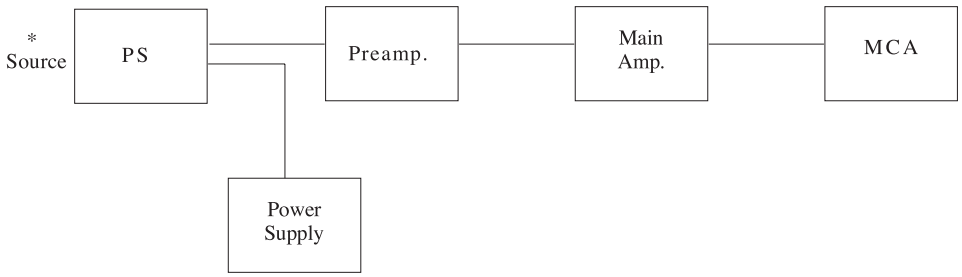

Figure 1a

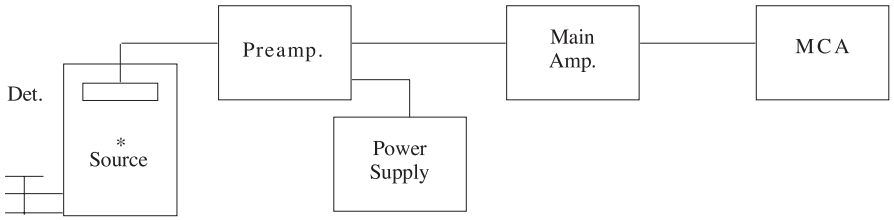

Figure 1b

Figure 1. (a) A block diagram of the beta PS spectrometer. (b) A block diagram of the beta Si SBD spectrometer.

The beta spectrometer with PS is composed of a Bicron BC-400 PS, an EG&G Ortec Model 401A BIN, Model 459 power supply, Model 113 preamplifier, Model 472 spectroscopy amplifier and Model Trump 8k MCA mounted in a PC for data collection.

BC-400 PS is a general purpose polyvinyltoluene scintillator, with 1.032g/cm^3 density, 12ns decay constant, 1.58 refractive index and 95% light output. The 3″x3″ BC-400 PS used in this work has a mylar entrance window with a thickness of 2 μm in order to protect it from the outer radiation. Together with these characteristics, BC-400 PS is recommended for beta spectrometers.

A Rexon 1200P model photomultiplier tube with plug in voltage divider positioned on the scintillator material and the plastic scintillation detector has been constructed by Rexon Components Inc.

With sensitive adjustments of power supply, preamplifier and main amplifier, pure beta pulse height spectra have been recorded in the MCA. In order to avoid extra pulses being produced due to temperature, the system was continuously cooled. All spectra were acquired at room temperature of 18 °C. During data acquisition, the plastic scintillation detector had been put into a light-tight chamber.^{90}Sr and ^{204}Tl spectra were acquired with the spectrometer having 3 mm PS.^{210}Pb and ^{14}C spectra have been taken from the spectrometer having 0.3 mm PS. The scintillator depths are enough to stop all betas from sources.

Data acquisition in beta spectrometry with PS has been performed in 5400s. The distance between the source and the detector has been fixed as 4 cm. Pure beta pulse height spectra have been stored in the PC, then subtracting the background peculiar to each source from the recorded spectra.

Similar to choosing the scintillator thickness with respect to incident particle energy, the sensitivity thickness of a semiconductor detector is determined as appropriate for the incident particle type and its energy. In connection with this, an energy-sensitive Si SBD (EG&G Ortec Model CA-018-050-100) which has an active area of 50 mm^2 and sensitive depth of 100 μm was used to detect pure ^{210}Pb and ^{14}C spectra. Moreover, in order to detect pure beta spectra of ^{90}Sr and ^{204}Tl sources, another SBD (EG&G Ortec Model CB-018-050-2000) which has an active area of 50 mm^2 and sensitive depth of 2000 μm was employed.

An EG&G Ortec Model 401A BIN, Model 428 power supply, Model 142 preamplifier, Model 472 spectroscopy amplifier and Model Trump 8k MCA mounted in a PC were used in the spectrometer with Si SBD. Signals from detector were amplified by preamplifier and shaped by main amplifier. The MCA has recorded the signals from the main amplifier. Si SBD was put into a vacuum chamber to protect the detector from light and the vacuum pump was operated 3 min. (<500 μm).

Si detectors are rather sensitive devices to operating temperature. Increasing temperature leads to leakage current in the detector. It is clear that cooling reduces the electronic noise in it and improves the resolution [5]. For this reason, the detection system was also cooled to prevent the spectrometer with Si SBD from generating extra pulses that might arise due to temperature in the system during measurement.

All measurements in Si SBD beta spectrometer were performed at room temperature of 18 °C, and detector-source distance was taken as 5 mm. Pure spectra from sources are separately recorded in MCA by performing appropriate adjustments of the detection system. With sources removed from the detection system, backgrounds peculiar to each source were collected. By means of subtracting these backgrounds from the source spectra, the pure beta pulse height spectra were obtained.

The standard beta sources used in the measurements have been purchased from Oxford Inc. The radioactive materials had an active area of 5 mm^2, a thickness of 5 mm embedded in a solid mylar disk of diameter of 25 mm. The information about the beta sources used in experiments is noted in Table.

Table. The list of beta sources used in experiments [33].

Isotope Name	Activity(μCi)	Half-Life (y)	Max. β Energy(keV)
^{204}Tl	10	3.80	766
^{90}Sr	0.1	28.00	546
^{210}Pb	0.1	22.00	61
^{14}C	10	5745.00	156

3. Results and Conclusions

In this work, beta-ray spectrometers employing PS and Si SBD were used. In the spectrometer with SBD, Si detectors with active depths of 100 μm and 2000 μm were employed for ^{14}C, ^{210}Pb and for ^{90}Sr,^{204}Tl isotopes, respectively. In the beta spectrometer with PS, material thicknesses of 3 mm and 0.3 mm were used to detect beta particles from ^{90}Sr, ^{204}Tl and from ^{14}C, ^{210}Pb sources, respectively.

By subtracting background from the acquired spectra at constant room temperature (18 °C) and continuous cooling, net beta responses of the spectrometers to the sources above were obtained.

The pure beta pulse height spectra which was obtained from the spectrometer with Si SBD and subtracted from background of ^{90}Sr, ^{204}Tl, ^{210}Pb and ^{14}C sources with no discrimination of noise is shown in Figures 2, 3, 4, 5, respectively. The pure beta spectra from the spectrometer with PS can be seen in Figures 6, 7, 8, 9, respectively. These spectra were also subtracted from background and have no discrimination to electronic noise. The energy of beta particles was measured over 1024 channels from all spectra.

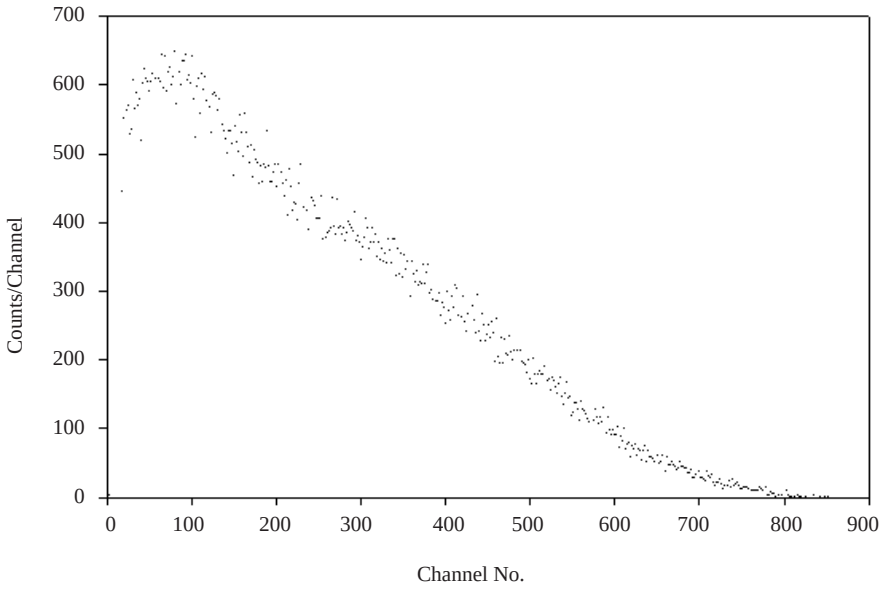

Figure 2. ^{90}Sr spectrum from the Si SBD spectrometer.

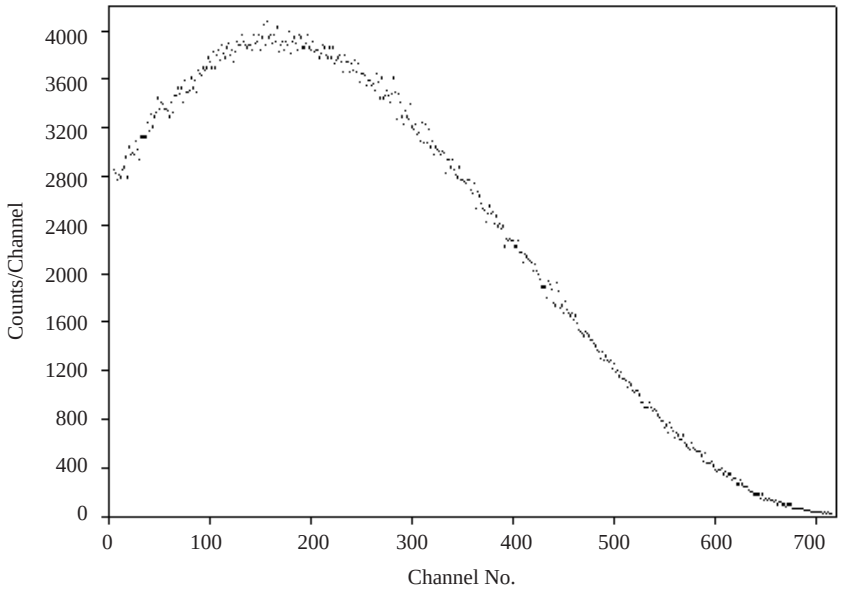

Figure 3. ^{204}Tl spectrum from the Si SBD spectrometer.

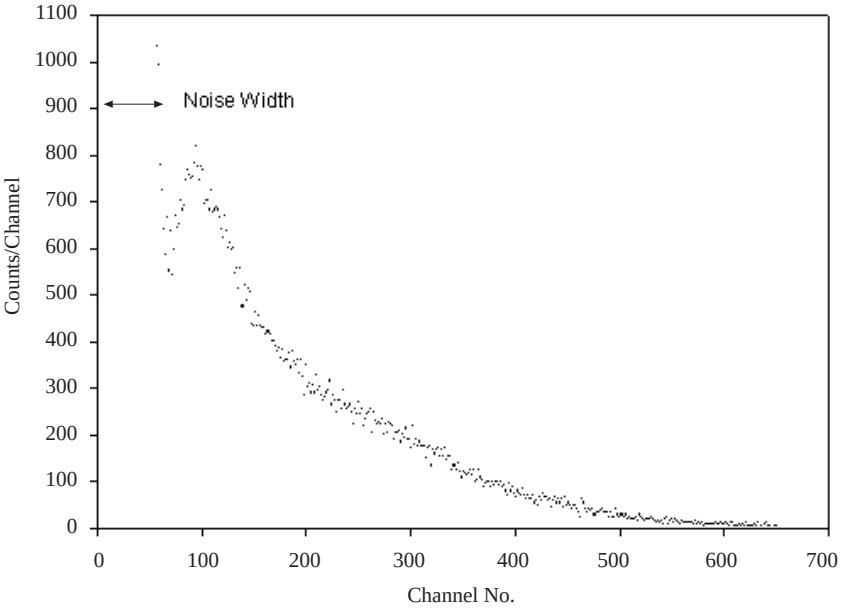

Figure 4. ^{210}Pb spectrum from the Si SBD spectrometer.

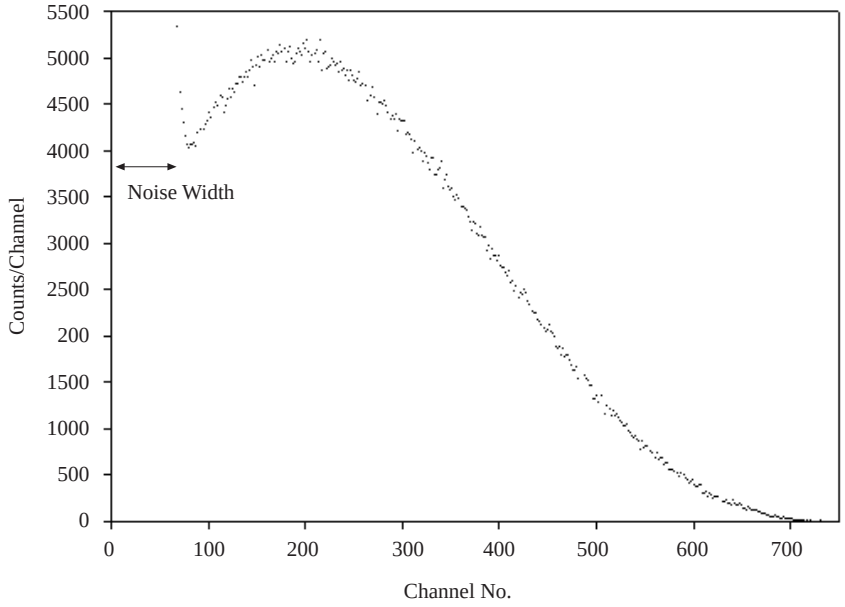

Figure 5. ^{14}C spectrum from the Si SBD spectrometer.

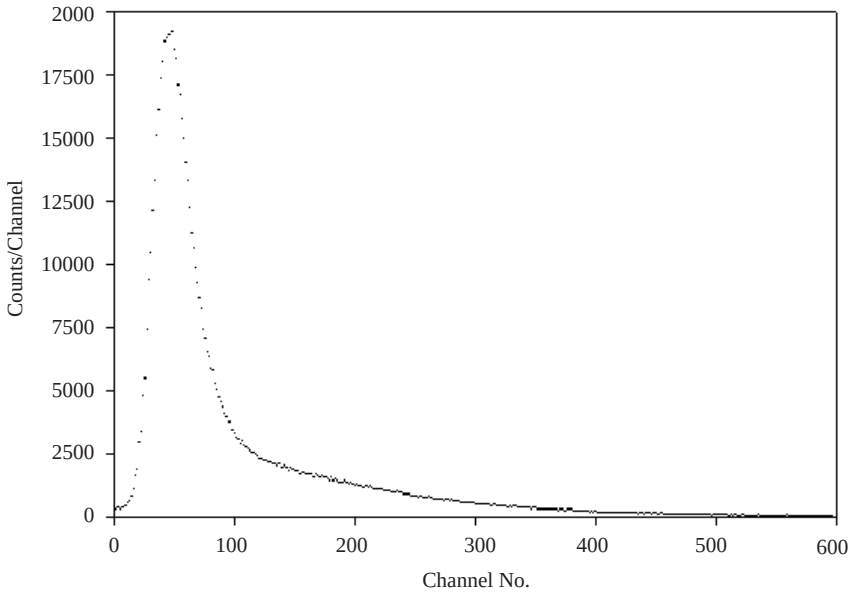

Figure 6. ^{90}Sr spectrum from the PS spectrometer.

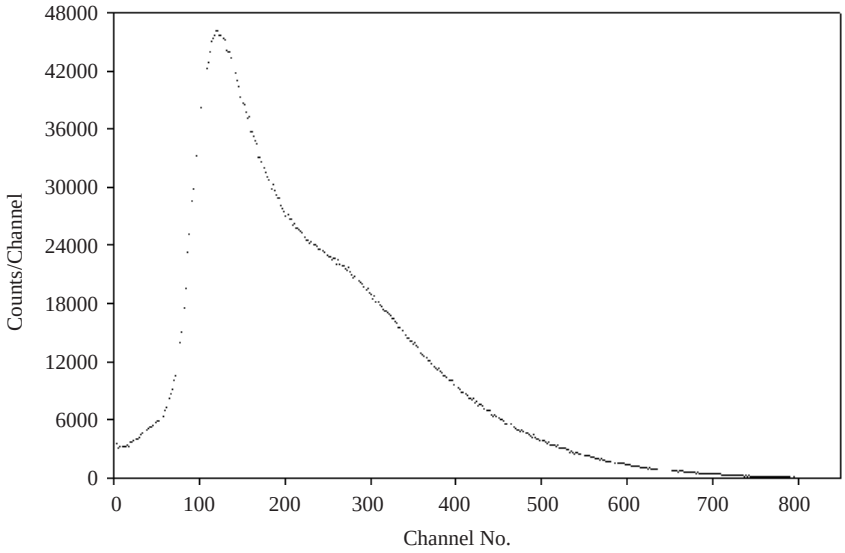

Figure 7. ^{204}Tl spectrum from the PS spectrometer.

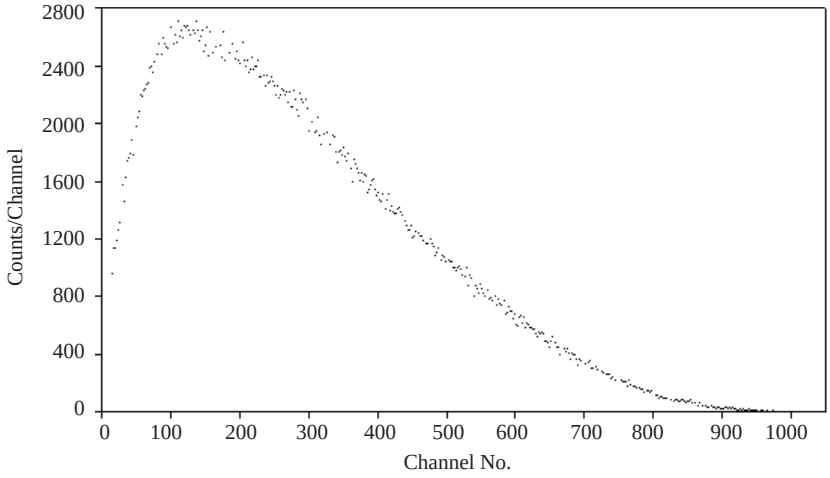

Figure 8. ^{210}Pb spectrum from the PS spectrometer.

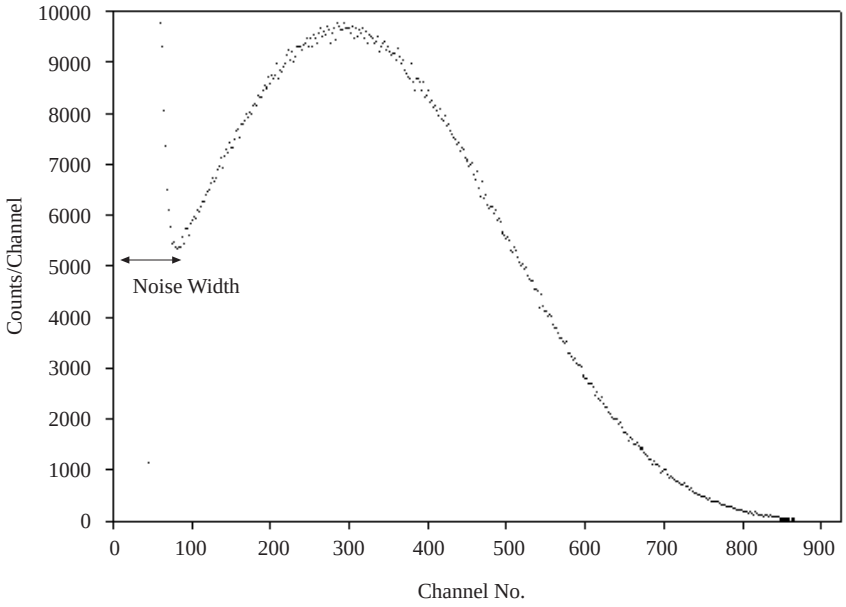

Figure 9. ^{14}C spectrum from the PS spectrometer.

^{14}C spectrum obtained from the spectrometer with Si SBD is more clear than Battens [26] spectra. Also,^{14}C spectra in this work, accord with the previous theoretical and experimental spectra [8,27,28,29,30]. The ^{14}C spectrum from the spectrometer with PS is more well-defined and less noisy that of the Si SBD beta spectrometer.

Since the ^{210}Pb spectrum from the PS spectrometer is less noisy compared to the Si spectrometer, it is believed that PS beta spectrometer is superior to the Si SBD beta spectrometer in this work.

When ^{90}Sr and ^{204}Tl pure beta spectra were compared with the previous spectra [30,13,3,14,31,32], the results from Si spectrometer are especially in good agreement with the spectra published in the literature, thus, perhaps, giving greater acceptability. Since maximum energies of beta particles from ^{204}Tl are higher than particles from the other sources, i.e. high-energy particles from ^{204}Tl in comparison with the other sources, it is believed that the sharp, low-energy peak in the spectrum from PS spectrometer arised from the backscattered particles from the detector surface.

In comparison with previous works, obtained results in this work are quite reliable in point of obtaining pure beta pulse height spectra.

When low-energy particles emitting sources were used, electronic noise in the spectrometer with Si SBDs became a rather important problem, highlighting their sensitivity to noise. The effect of noise can be reduced by cooling [4]. However, if cooled excessively, the detector may suffer structural damage. Thus, cooling must be done within limits.

In order to support the data to be used in theoretical calculations related to the beta particles and results obtained from these calculations, pure beta spectra have been studied and researched in two types of spectrometers.

References

[1] O. Olsson, E. Holm and L. Botter-Jensen, *Appl. Radiat. Isot.* **43(1/2)** (1992) 77-82.

[2] M. Groβ, P. Jürgens, U. Keyser, S. Kluge, M. Mehrtens, S. Müller, F. Münnich, J. Wulff and H.R. Faust, *Nucl. Instr. and Meths.* **A311** (1992) 512-519.

[3] M. Palazzolo, P. Prati, G. Ricco and M. Taiuti, *Health Phys.* **62(2)** (1992) 155-161.

[4] E. Holm, J. Rioseco, S. Ballestra and I. Wilmet, *The Sci. Tot. Environ.* **69** (1988) 61-77.

[5] E. Holm, Alpha and beta spectrometry with surface barrier and ion implanted detectors. Proceedings of the first international summer school La Rabida, Huelva, Spain, (1987) 418-443.

[6] Y.S. Horowitz, Y. Weizman and C.R. Hirning,*Nucl. Instr. and Meths.* **A371** (1996) 522-534.

[7] M.G. Gornov, Yu B. Grov, S.V. Dovgun and V.G. Sandukovskii, *Instr. And Exp. Tech.* **37(3)**, Part 1, (1994) 291-293.

[8] E.I. Vapirev, D. Sueva, V. Spassov, N. Chikov and I. Ivanov, *Appl. Radiat. Isot.* **45(4)** (1994) 453-459.

[9] J. Axelsson and C.T Reimann, *Nucl. Instr. and Meths.* **B93** (1994) 499-504.

[10] Th. Frommhold, W. Arnold, H. Friedrichs, R. Göbel, R.D. Heil, U. Kneissl, U. Seemann, F. Steiper, and C. Kozhuharov, *Nucl. Instr. and Meths.* **A310** (1991) 657-664.

[11] J.L.W. Petersen,*Nucl. Instr. and Meths.* **221** (1984) 582-585.

[12] K.L. Swinth, L.A. Rathbun and L.W. Brackenbush, *Radiat. Prot. Dos.* **14(2)** (1986) 105-108.

[13] Y.S. Horowitz, C.R. Hirning, P. Yuen and M. Aikens, *Nucl. Instr. And Meths.* **A338** (1994) 522-533.

[14] K.L. Swinth, R.D. Sisk and G.G Simons, *IEEE Trans. Nucl. Sci.* **36(1)** (1989) 1166-1171.

[15] D.E. Martz, B.L. Rich and O. Johnson, *Radiat. Prot. Dos.* **14(2)** (1986) 183-186.

[16] G.G. Simons and J.F. Higginbotham, *Nucl. Instr. and Meths.* **A293** (1990) 551-554.

[17] Jr.P.F Mantica, B.D. Kern, B.E. Zimmerman, W.B. Walters, J. Rikovska and N.J. Stone, *Hyperfine Interact.* **75** (1992) 415-421.

[18] Yu.K. Akimov, *Phys. Part. Nucl.* **25(2)** (1994) 210-233.

[19] F. Titus, *Nucl. Instr. and Meths.* **89** (1970) 93-100.

[20] F.K. Wohn, J.R. Clifford, G.H. Carlson and W.L.Jr. Talbert, *Nucl. Instr. and Meths.* **101** (1972) 343-352.

[21] W.R. Leo, Techniques for Nuclear Particle Physics Experiments, (Springer-Verlag, Berlin, 1994), 164.

[22] E. Steinbauer, P. Bauer, M. Geretschlager, G. Bortels, J.P. Biersack and P. Burger, *Nucl. Instr. and Meths.* **B85**, (1994) 642-649.

[23] W.E. Drummond and J.L. Moll, *J. Appl. Phys.,* **42(13)** (1971) 5556-5562.

[24] H.R. Zulliger, *J. Appl. Phys.* **42(13)** (1971) 5570-5577.

[25] G.F. Knoll, Radiation Detection and Measurements. John Wiley and Sons, (New York, 1979), 386.

[26] J.R.Batten, *Nucl. Instr. and Meths.* **A277** (1989) 478-484.

[27] F. Ortiz, J.M. Los Arcos, A. Grau and L. Rodriguez,*Nucl. Instr. and Meth.* **A312** (1992) 109-113.

[28] H. Yamamoto, Hatekeyama, T. Norimura and T. Tsuchiya, *Nucl. Instr. and Meth.* **A281** (1989) 128-132.

[29] H. Yamamoto, Hatekeyama, T. Norimura and T. Tsuchiya,*Nucl. Instr. and Meths.* **B53** (1991) 178-183.

[30] J. Mantel, *Int. J. Appl. Radiat. Isot.* **23** (1972) 407-413.

[31] M.J. Berger, M.P. Unterweger and J.M.R. Hutchinson, *Nucl. Instr. and Meths.* **A369** (1996) 684-688.

[32] A.C. Mischra and N.J. *Parks, Appl. Radiat. Isot.* **38(6)** (1987) 455-461.

[33] C.M. Lederer, J.M. Hollander and I. Perlman, Table of Isotopes, Sixth Edit. (John Wiley and Sons, New York 1967).