First tests of the big volume ultra low background gamma spectrometer

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1. Introduction

- Even in the absence of a radioactive source, germanium spectrometer exhibits certain counting rate,caused by natural radioactive elements distributed in the surrounding of the detector and by cosmic rays. The naturally occurring radioactivity originates from 3 radioactive chains ^{232}Th, ^{238}U and ^{235}U, and from ^{40}K. Natural potassium contains 0.0117% of ^{40}K emitting the 1460.8 keV gamma quanta. Very often, this line is one of the major background components.

- Lead, which is often used as shielding material, may contain ^{210}Pb which will contribute to the background , mainly the by the bremsstrahlung of its daughter ^{210}Bi. The responsibility of the manufacturer is to reduce the radioactivity of detector itself and of passive shield by careful selection of radiopure materials.

- The neutrons produced by cosmic rays can manifest themselves by different nuclear reactions characterized by gamma lines. That can be the inelastic scattering of fast neutrons ((n,n,) reactions), or absorption of thermal neutrons ((n,γ) reactions).

2. Experimental results and discussion

- The ultra-low background, big volume germanium spectrometer, made by Canberra is located in the surface laboratory of Department of Physics in Novi Sad (Fig.1). It has 100% relative efficiency (the same absolute efficiency as 3"x 3" NaI(Tl) detector at 1332 keV),what corresponds to about 380 cm^3 of detector active volume. The front window of detector end-cap is only 0.89 mm thick and it is made of an high-strength carbon fiber composite , which provides greater than 85 % transmissions for photon energy above 15 keV, and nearly 100% transmissions for photon energy above 20 keV. The spectrometer is closed-end coaxial type with U-style cryostat configuration.

Fig.1 *View of the ultra low-background germanium spectrometer (a) ;*

- Detector shield is constructed with layered bulk lead. The outer five inches (125 mm) is ordinary low-background lead while the innermost one inch (25 mm) is selected for ^{210}Pb content of about 20 Bq/kg. The passive shield has a inner lining to stop the lead K-shell X-rays in the energy range of 75-85 keV. Lining materials (Fig. 1 b) are low-background tin with a thickness of 1 mm, and high purity copper with a thicknesses of 1.5 mm. Also, the Sn X-rays (25 -28 keV) are reduced by copper.

- The shield is equipped with a gas port for the introduction of nitrogen from Dewar vessel to flush the shield interior and reduce background from radon and radon daughters. The total mass of the shield is 1633 kg.

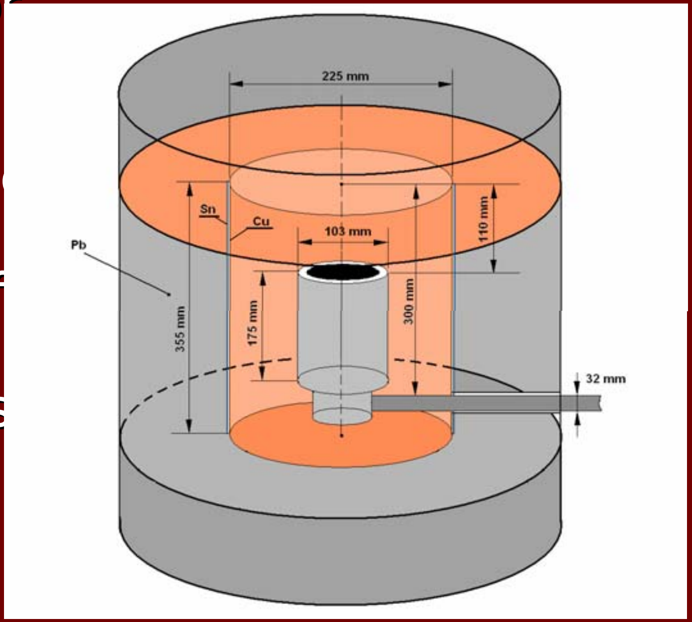
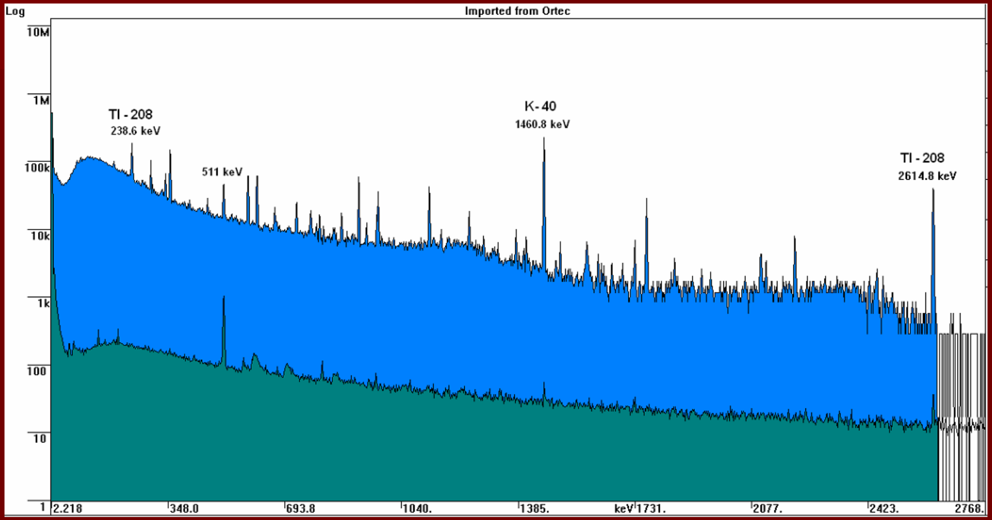


Fig 1b. Position of the detector housing inside lead shield

- The comparison between background spectra of bare detector and shielded detector is presented on Fig. 2.
- Vertical axis represents the total number of registered events, while the horizontal axes represents the energies of gamma quanta in keV. The acquisition time was 517 ks.
- The reduction factor found for the complete spectrum, in the range of 40keV to 2768keV was 238.
- The 511 keV annihilation line is reduced less than the other environmental background lines due to its cosmic origin.



•Fig.2. Background spectra of bare big volume Ge detector (upper spectrum) and shielded detector (lower spectrum)

Table 1.Comparison of intensities for several significant gamma lines

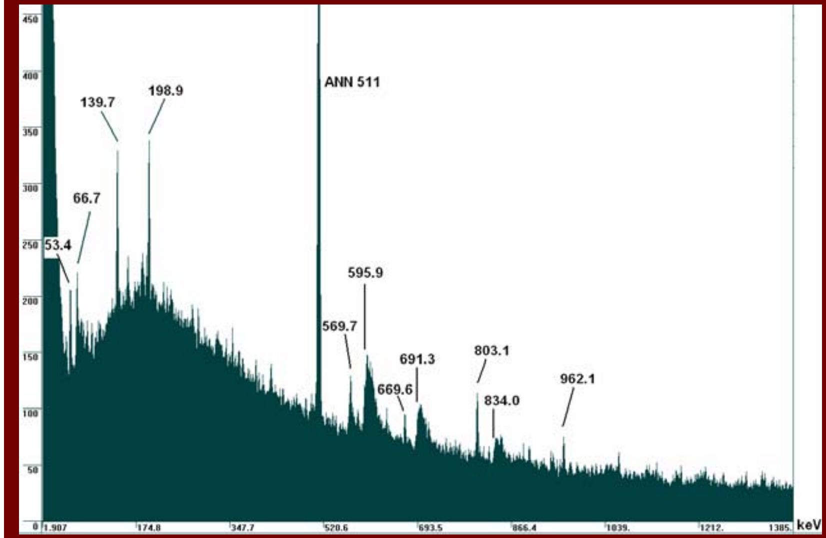
Energy [keV]	Intensity [c/ks] (unshielded detector)	Intensity [c/ks] (shielded detector)	Reduction factor
511 ANN	622.6±58.6	30.42±0.514	20.47
351.9 **Pb-214**	1883.33±82.1	0.392±0.192	4799.56
1460.8 **K-40**	5676.7±94.8	0.4236±0.112	13401.01
2614.4 **Tl-208**	1295.2±44.5	0.718±0.103	1802.98
40 - 2768	341000	1430	238.46

- The most prominent gamma lines in the background of shielded big-volume Ge spectrometer are neutron induced lines (Fig.3). These lines are listed in Table 2. Their intensities are compared with corresponding background lines of 32 % relative efficiency Ge detector shielded by lead (wall thickness 12 cm, inner layers Sn (3.5 mm)+ Cu (0.5 mm), total mass 708 kg).

Table 2.The intensities of neutron produced background gamma lines in Ge detectors of relative efficiencies 100% and 32% . The ratios of intensities are given in 5-th column.

Reaction	Intensity [c/ks]; 100% rel.eff.	Intensity [c/ks]; 32% rel.eff.	$I_{100\%} / I_{32\%}$
72Ge(n,γ)73mGe	1.799±0.257	< 0.374787	> 4.8
72Ge(n,γ)73mGe	1.59±0.255	1.554±0.21	1.02
74Ge(n,γ)74mGe	1.891±0.30	0.423±0.19	4.46
70Ge(n,γ)71mGe	2.437±0.314	0.542±0.24	4.50
207Pb(n,n')207Pb	0.7587±0.22	<0.298	> 2.55
74Ge(n,n')74Ge	16.24±0.63	0.451±0.125	36
63Cu(n,n')63Cu	0.567±0.17	<0.263	> 2.16
72Ge(n,n')72Ge	7.51±0.53	0.893±0.23	8.42
206Pb(n,n')206Pb	1.051±0.16	0.258±0.11	4.08
72Ge(n,n')*72Ge	3.31±0.445	<0.225	> 14.7
63Cu(n,n')63Cu	0.553±0.17	0.303±0.13	1.82

Fig.3. Gamma lines produced by neutrons in (n,n,) reactions and (n,γ) reactions. The numbers near the peaks represent energies in [keV].



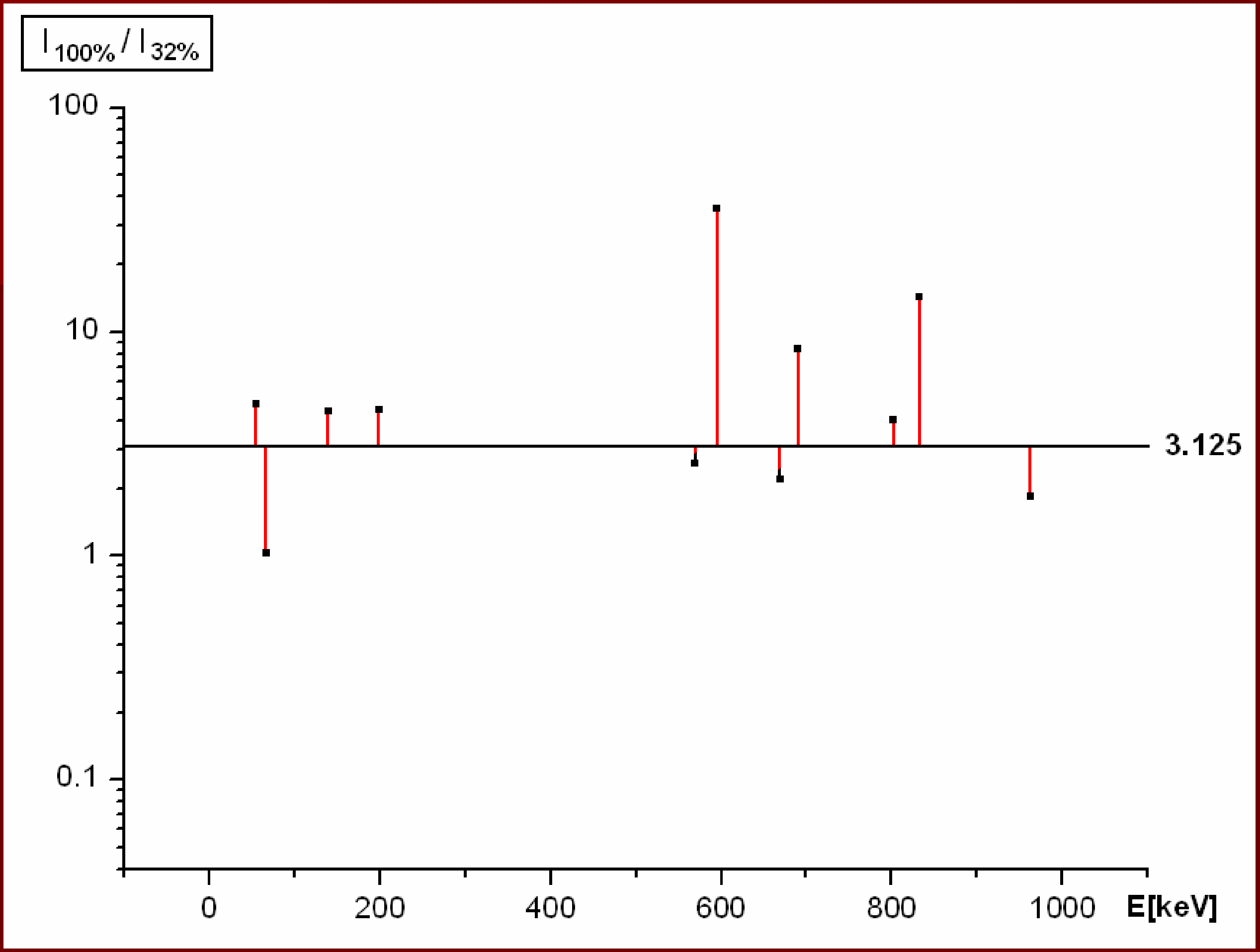


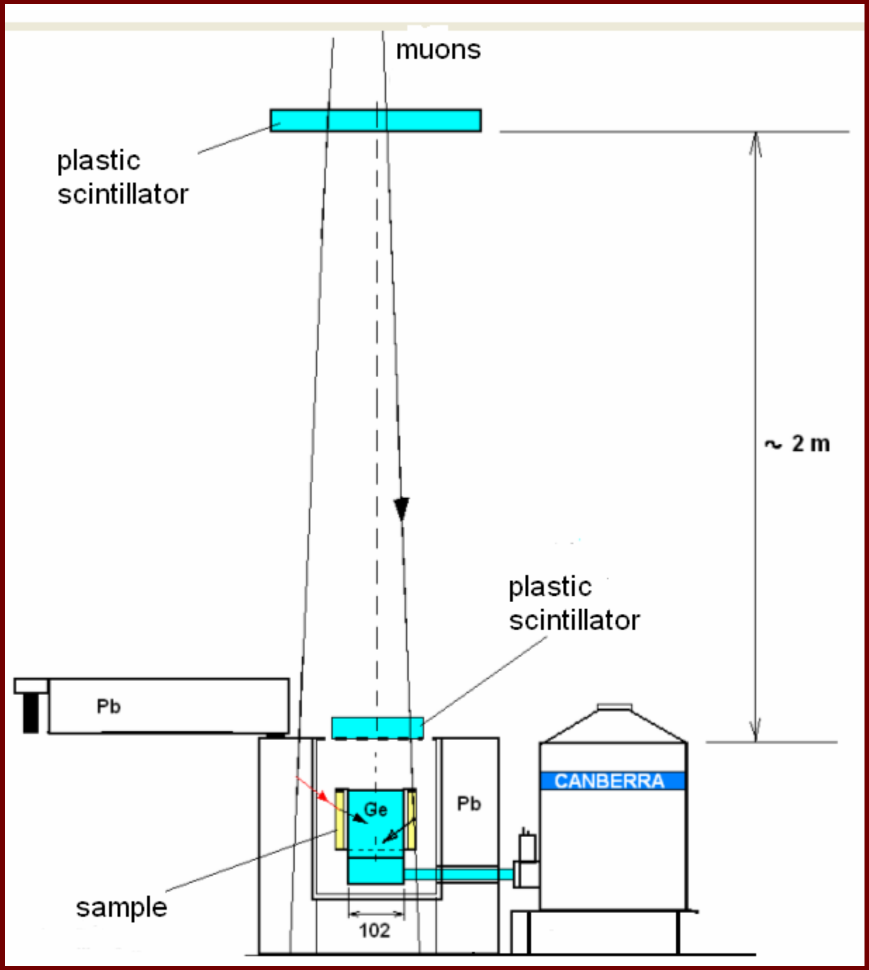
Fig.4. The ratio of intensities of neutron induced lines in 100% relative efficiency Ge detector and 32% relative efficiency Ge detector ,respectively .
Value 3.125 is the ratio of relative efficiencies for two detectors.

- The comparison of several background lines intensities and integral count rates for big volume detector and 32% relative efficiency detector is presented in Table 3.

Table 3.

Energy [keV]	Intensity [c/ks] (shielded big-volume detector)	Intensity [c/ks] (shielded 36%relative efficiency detector)	Ratio of intensities; $I_{100\%} / I_{32\%}$
511 ANN	30.42±0.514	12.4±0.26	2.45
238.6 **Pb-212**	0.446±0.25	0.40±0.16	~ 1.12
351.9 **Pb-214**	0.392±0.192	< 0.36	~ 1.1
1460.8 **K-40**	0.4236±0.112	1.36±0.1	0.31
50 keV-1800 keV	1300	880	1.48

- For the future purpose, the ultra-low gamma spectrometer will be upgraded by two plastic scintillators (Fig.5). These two plastics and Ge detector will operate in the coincidence mode. In such configuration, system will be used for the investigation of different processes induced by direct interaction of cosmic muons and certain materials.



3. Conclusions

- The new ultra-low background big volume gamma spectrometer exhibits very good performances. From comparison with another ultra-low background system of 32% relative efficiency Ge spectrometer (Tab.3) it is obvious that the new system has lower integral count rate and lower intensities of background lines (having in mind efficiencies ratio of 3.125 for these two detectors).

- For the reduction of neutron induced gamma lines relatively thin layers of materials with high concentration of boron will be used.

- A good example are only 3.2 mm thick FLEX BORON silicon sheets , which contain 25 weight-percent of uniformly distributed boron with high cross section for thermal neutrons .