On the Feasibility of Low-Background Ge – NaI Spectrometer for Neutrino Magnetic Moment Measurement

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Abstract

We analyze the possibility of using a low-background Ge – NaI spectrometer in a reactor experiment for a search for neutrino magnetic moment down to $3 \times 10^{-11}$ of the electron magneton. The properties of the so-far existing Ge low-background spectrometers are discussed and additional sources of background in a reactor experiment at a small depth are estimated. These estimates place specific requirements on the design of the spectrometer. The results of preliminary background measurements at a small depth of 5 m.w.e. with a dedicated spectrometer built in ITEP are reported.
1 Introduction

A non-zero magnetic moment of neutrino would be a fundamental physical quantity, whose implications could lead well beyond the standard picture of interactions of elementary particles and to non-standard phenomena in astrophysics.

The recent renewed interest to the problem of the neutrino magnetic moment (NMM) is in a large part related to the peculiar behavior in time of the solar neutrino flux measured in the Cl–Ar experiment\(^1\). One interpretation of this behavior is that the measured flux anti-correlates in time with the solar activity\(^2,3\). Such an anti-correlation could be explained\(^4\) by interaction of NMM with the time-dependent magnetic field in the Sun’s convection zone. For the magnetic field in the convection zone in the range \((1 \div 10)\) KGs this mechanism is operative if the magnetic moment of the electron neutrino is \(\mu_\nu \sim \left(10^{-10} \div 10^{-11}\right)\mu_B\), with \(\mu_B = e/(2m_e)\) being the Bohr magneton. Such value of the NMM would be by several orders of magnitude bigger than the minimal Standard Model predicts for a massive neutrino\(^5\):

\[
\mu_\nu = \frac{3eG_F}{8\sqrt{2}\pi^2} m_\nu \approx 3 \times 10^{-19} \mu_B \frac{m_\nu}{1\text{ eV}}.
\]  

However in a number of extensions of the theory beyond the minimal Standard model (see e.g. \(^6\)) one can readily achieve the NMM of the required magnitude, not necessarily related to the neutrino mass\(^7\).

The present direct laboratory limit for the NMM for electron antineutrino is derived from reactor neutrino experiments\(^8,9,10\): \(\mu_\nu \leq \left(2 \div 4\right) \times 10^{-10}\mu_B\). More stringent limits on NMM are found from astrophysical analyses\(^11\). Such analyses are typically based on the fact that at late stages of stellar evolution at densities above \(10^5 \text{ g cm}^{-3}\) practically all energy loss by the star is due to neutrino emission. Thus an NMM would add an electromagnetic component to neutrino interaction with matter inside the star and by that significantly modify: the overall rate of cooling, the critical mass of a He star, the duration and the energy spectrum of the neutrino burst from a supernova, etc. One should keep in mind however that though the astrophysical bounds are rather strong: \(\mu_\nu \leq \left(0.01 \div 0.1\right) \times 10^{-10}\mu_B\), they still rely on model dependent assumptions\(^12,13,14\). Therefore it is still very relevant to improve the sensitivity of direct laboratory measurements of the NMM, presumably down to \(10^{-11}\mu_B\).

A laboratory measurement of the NMM is based on its contribution to the (anti)neutrino - electron scattering. For a non-zero NMM the differential over the kinetic energy \(T\) of the recoil electron cross section \(d\sigma/dT\) is given by the sum of the standard weak interaction
cross section (W) and the electromagnetic (EM) one (see equations (4) and (5) below). At a small recoil energy \( T \ll E_\nu \) these two components behave in a distinctly different way: the weak part, \( (d\sigma/dT)_W \), is practically constant, while the electromagnetic one, \( (d\sigma/dT)_{EM} \) grows as \( 1/T \) towards low energies. Therefore for improving the sensitivity to \( \mu_\nu \) it is necessary to lower the threshold for detecting the recoil electrons as far as the background conditions allow. In the experiments [8, 9, 10] the effective range of the detected energy of the electrons was \( T = (1.5 - 5.2) \text{ MeV} \) because of a sharp increase of the background at lower energy. In the currently proposed experiments [15, 16], the threshold for registration of the electrons is expected to be significantly lower: \( T_{\text{min}} = (0.2 - 0.6) \text{ MeV} \). The purpose of this paper is to show that for experiments with the electron antineutrinos from a reactor a much better sensitivity to \( \mu_\nu \) per mass of the detector can be achieved with a low background germanium spectrometer (LBGS) capable of setting the effectively measurable recoil energy range \( T = (3 - 50) \text{ KeV} \). Similar spectrometers are being used for experiments with double beta decay and in search for weakly interacting dark matter. A detector of this type dedicated to the search for NMM is being constructed in ITEP and we report here on its thus far measured parameters.

In section 2 we discuss general characteristics of Ge spectrometers that make them suitable for low-background measurements, in particular for detecting rare events with total energy deposition below 100 KeV. As existing samples of analogous detectors we discuss the double beta decay and the dark matter detectors.

In section 3 and 4 is discussed the specifics of low-background measurements in a close proximity of a nuclear reactor. We evaluate the cosmic background conditions and background from inverse beta decay process with reactor antineutrino. We evaluate also the event rates from the reactor antineutrinos induced by the weak interactions as well as by their hypothetical electromagnetic interaction. Based on these considerations we give reasoning for the chosen design of the spectrometer assembly and estimate its sensitivity to NMM.

In section 5 we estimate the expected effect of the NMM in the spectrometer and compare it with the realistically achievable background. This allows to evaluate the possible limits of the sensitivity in the experiment to the NMM.

In section 6 are described the design and the parameters of the built in ITEP spectrometer with active NaI(Tl) shielding. We report the results of tests of the spectrometer in a low-background laboratory in ITEP at the depth of 5 m.w.e.

\(^1\)There is no interference between these two contributions for a massless neutrino, since the helicity of the final neutrino in a weak scattering process is opposite to that in a process induced by the NMM.
2 Background Characteristics of Germanium Spectrometers

In detecting very rare events with the rate of less than one event per day extreme care should be taken with regards to the natural radioactivity background. This includes using in the construction of the detector highly purified materials, placing the experiment in special low-background chambers and applying appropriate selection criteria to the events.

The advantage of using Ge calorimeters in low-background measurements is partly based on their high energy resolution $\Delta E/E = 10^{-3}$ and for the most part on the availability of Ge crystals of extreme purity: the fractions of radioactive impurities in the Ge crystal are less than $10^{-14}$. A Ge spectrometer can contain either one mono-crystal detector with mass up to 3 kg, or it can be an assembly of few such detectors with the total mass (8 - 15) kg. Since the detectors are quite compact: the total volume usually does not exceed 4 l, it is possible to use in its shielding rare and expensive materials: refined electrolytic copper, highly purified titanium, crystallic silicon, old lead, which is practically free of the radioactive isotope $^{210}Pb$.

As an active shielding against the charged and the compton components of the background are used $NaI(Tl)$ scintillators. These special measures allow to reach very low radiation background in the double beta decay and dark matter experiments.

Generally the background spectra of gamma detectors display a growth of the compton component of the background towards lower energies. This is caused by the character of the external radiation background and by the growth of the detection efficiency at lower energy of the gamma quanta. In Ge detectors with the surface contact of the n type this growth of the background becomes slow at energies (150 - 200) KeV and can turn into a decrease at lower energies. This is explained by the existence of a passive surface layer with thickness (0.5 - 1.5) mm in n-p detectors. In other words the Ge crystal has its own passive shielding that absorbs soft external gamma radiation.

In the range of energies between 3 KeV and 10 KeV the main sources of the background are usually the microphonic and electronic noises. The microphonic noise is caused by vibrations of the detector including the vibrations induced by the boiling and the turbulent flow of the liquid nitrogen used as coolant for the detector. The sources of the electronic noise are the fluctuations of the detector leakage current and the thermal noise of the FET. The background from the microphonic and the electronic noises is very efficiently suppressed by the event pulse shape analysis\cite{17}.

The remaining background at energies (2 - 100) KeV is determined by the compton
continuum and the elastic and inelastic scattering of neutrons on Ge. The suppression of these components of the background to a great extent depends on the design of the spectrometer. The existing installations can be classified into two major types: those with a passive shielding (PS) and those with an active shielding (AS). An example of the first type of spectrometer is the installation built by the USC/PNL collaboration\cite{18}, where two Ge detectors in copper cryostats are simply placed in a lead housing with 40 cm thick walls. However the construction of this spectrometer is based on the profound expertise of the PNL group in building low-background detectors using super pure materials. In this installation the inner 10 cm of the passive shielding is made of a very old lead from a sunken Spanish galleon. Major elements of the construction (the cryostat, cold finger) are manufactured from electrolytic copper. In the process of electrolysis from a CuSO$_4$ solution the copper is purified chemically with high efficiency thus practically removing the contamination by $U-\text{Th}$ admixtures and by cosmogenic elements produced by the cosmic rays. During the delivery to the underground site the time the components spent on the surface was minimized and also the delivery by airplane was excluded, since the rate of generation of the cosmogenic elements grows by orders of magnitude at high altitude. As a result after one year of conditioning of the spectrometer in the underground laboratory the USC/PNL spectrometer had produced then lowest achieved background count rate of 0.2 events/(KeV kg year) at the energy about 2 MeV.

An example of an AS installation can be the SB/LBL spectrometer\cite{19} for the search for double beta decay of $^{76}\text{Ge}$. The spectrometer is based on 8 Ge detectors with the volume 160 - 180 cm$^3$ each, surrounded by an active shielding consisting of 10 NaI(Tl) scintillator modules , which in turn is inside borated polyethylene surrounded by a 20-cm-thick Pb shielding . The veto signals from the scintillators suppressed the cosmic background. The measurements were taken at the depth of 600 m.w.e. where the cosmic background was still significant. However the main purpose of the AS was the suppression by a factor 10 - 20 of the compton component of the radiation background. Thus the scintillator AS makes the spectrometer less demanding with respect to purity of the passive shielding and of the rest of the components of the spectrometer.

Subsequently both spectrometers were used in the search for dark matter. This had required to lower the threshold down to 4 KeV and to suppress the background at low energies. As a result the achieved rate of the background in the energy range (4 - 100) KeV in the USC/PNL and SB/LBL spectrometers was respectively 0.1 events/(KeV kg day) and 0.4 events/(KeV kg day). If it were possible to have such level of the background counts in
a spectrometer located near a nuclear reactor, it would allow to significantly improve the
sensitivity to the NMM in comparison with the present bounds\cite{8,9,10} from reactor experi-
ments. However, at much smaller depth and near the reactor the background conditions are
significantly worsened by two factors: a larger cosmic background and the background from
the reactor itself. Thus far there is no known experience of doing low-background measure-
ments in such conditions, therefore a quantitative understanding of the influence of these
sources of the background requires a separate study.

3 Estimates of the background in a LBGS from the
cosmic rays

The inherent background is practically the same in AS and PS spectrometers. Therefore the
choice of the type of shielding of a LBGS depends on the ability to suppress the external
background from the cosmic rays and from the working nuclear reactor. The resultant
background is sensitive to a number of factors such as the exact position of the spectrometer
relative to the reactor, the thickness of the layers of the passive and the active shielding
and the order in which these layers are sandwiched, the presence in the spectrometer of
materials containing hydrogen, etc. Therefore our comparative estimates of the background
and thus of an achievable sensitivity to the NMM in these two types of spectrometers are
made under the following assumptions:

- The mass of the Ge crystal is 2 kg;
- The mass of the passive lead shield is 10 t;
- The flux of the antineutrinos from the reactor at the detector is $2 \times 10^{13} \nu/cm^2 sec$;
- The installation is located under the reactor at the depth of 20 m.w.e.;
- The thermal neutron background is completely suppressed by the passive shield of the
  experimental pavilion;
- The time of experiment consists of 300 days of the reactor on time and 70 days of the
  reactor off time.

At a reactor site there is a possibility to place the spectrometer under the reactor, so that
the whole reactor assembly provides a shielding from the cosmic background with effective
thickness of 10 - 40 m.w.e. At the assumed here effective depth of 20 m.w.e. the hadronic component of the cosmic background is already very small, and thus background is dominated by the flux of muons. The counts due to passage of the muons through the spectrometer and their decay inside the spectrometer can be easily vetoed out. The most significant remaining source of the background is the muon capture in the shielding and in the detector itself due to the reaction \[ \mu^- + (Z, A) \rightarrow (Z - 1, A)^* + \nu_\mu \]
\[ \rightarrow (Z - 1, A - x) + x \text{n}, \]  
where \( x = 0, 1, 2, \ldots \).

In the capture process a new nucleus is produced and on the average 1.6 neutrons (in Pb) with energy from 6 MeV to few tens of MeV. The muon capture and the interactions of the secondary neutrons and the gammas in the detector are separated in time and can not be vetoed by external counters. The rate of the muon capture events at 20 m.w.e. is 60 events/kg day \[20, 21\]. Thus in 10 tons of a passive shielding there will be produced \(10^6\) neutrons per day. The probability for these neutrons to get into the detector depends on the geometry of the installation and on the presence of a moderator and absorber layer between the the lead shield and the detector. The muon capture in the germanium crystal, through the reaction (2) produces gallium, whose isotopes undergo beta decay with the periods \(T_{1/2}\) from 30 sec to 14 hours. The results of the estimates of the background from the \(\mu\) capture and at 20 m.w.e. and of the inherent background of the detector in spectrometers with AS and with PS are summarized in the Table 1.

One can see from the Table 1 that an AS spectrometer at 20 m.w.e. is practically insensitive to the cosmic background. This is due to the action of an internal shielding containing borated polyethylene, which moderates and captures the neutrons produced in lead. It looks realistic that a background level of 10 - 15 events/kg day can be achieved in AS spectrometers by lowering the inherent background of the spectrometer. The number used here is based on the measurements with the SB/LBL installation, which are 10 years old. During this period there were many changes in practice of low background measurements and antiradon shielding became the necessary element of such spectrometers, so it is plausible that a hermetization and filling the SB/LBL spectrometer with gaseous nitrogen would have significantly reduced the inherent background.
Background (events /kg day) in the energy interval 4 - 50 KeV

|                        | PS spectrometer | AS spectrometer |
|------------------------|-----------------|-----------------|
| Inherent background    | 5               | 20              |
| Background from $\mu$ capture in the shielding | 6 | 60 | 2 |
| Background from $\mu$ capture in the Ge detector | 3 | 3 |
| Total background       | 68              | 25              |

Table 1: Summary of the inherent and cosmic background rates in spectrometers with passive shielding and with active shielding at the depth of 20 m.w.e.

4 Background correlated with the reactor activity

In the proposed here experiment the effect of the NMM is extracted from comparison of the spectrometer counts with active reactor and with the reactor shut down. Therefore the background correlated with the reactor activity requires special attention since it would simulate the effect. The experience of the reactor neutrino oscillation experiments shows that the thermal neutrons from the reactor are efficiently absorbed by the passive shielding of the experimental pavilion. The most serious source of the background thus would come from the inverse beta decay process with the reactor antineutrinos:

$$A(Z + 1, N - 1) + \bar{\nu}_e \rightarrow A(Z, N) + e^+,$$  \hspace{1cm} (3)

which produces inside the installation unstable isotopes and the positrons. Most prone to generating this type of background are materials containing hydrogen, since the cross section of inverse beta decay on protons is by two orders of magnitude larger than the cross section of the $\bar{\nu}_e e$ scattering. The only element of the construction containing hydrogen is the borated polyethylene in the AS spectrometer. We estimate that the reaction (3) in this part of the spectrometer will contribute $\sim 10^{-3} \text{ events/kg day}$ to the background correlated with the reactor activity. In order to estimate the background from the inverse beta decay in other elements of construction we evaluated the cross sections of the reactions $Ge \rightarrow Ga$, $Pb \rightarrow Tl$, $Cu \rightarrow Ni$, $Na \rightarrow Ne$, and $I \rightarrow Te$. For all these nuclei the cross section does not exceed $1.2 \times 10^{-45} \text{ cm}^2$ and the total contribution to the background is $\sim 5 \times 10^{-3} \text{ events/kg day}$. 7
5 The effect of elastic $\bar{\nu}_e e$ scattering

The differential cross section for the elastic $\bar{\nu}_e e$ scattering associated with the electromagnetic interaction due to the hypothetical NMM is given by

$$\frac{d\sigma_{EM}}{dT} = \left( \frac{\mu_\nu}{\mu_B} \right)^2 \frac{\pi \alpha^2}{m_e^2} \left( \frac{1}{T} - \frac{1}{E_\nu} \right),$$

while the standard weak cross section is

$$\frac{d\sigma_W}{dT} = \frac{G_F^2 m_e}{2\pi} \left[ \left( 1 - \frac{T}{E_\nu} \right)^2 \left( 1 + 2 \sin^2 \theta_W \right)^2 + 4 \sin^4 \theta_W - 2 \left( 1 + 2 \sin^2 \theta_W \right) \sin^2 \theta_W \frac{m_e T}{E_\nu^2} \right],$$

where $E_\nu$ is the energy of the incident antineutrino, $T$ is the kinetic energy of the recoil electron, and $\theta_W$ is the Weinberg angle.

For the range of $T = (3 - 50) \text{ KeV}$ one can neglect in eq.(4) the term $1/E_\nu$ in comparison with $1/T$ and find the total EM cross section associated with the NMM as

$$\sigma_{EM} = 7 \times 10^{-45} \text{ cm}^2 \left( \frac{\mu_\nu}{10^{-10} \mu_B} \right)^2.$$  

Thus the excess of the scattering events due to the NMM in this range of $T$ and assuming the antineutrino flux $F = 2 \times 10^{13} \nu/\text{cm}^2 \text{ sec}$ is estimated as 0.3, 0.5, and 0.8 events/kg day for $\mu_\nu$ respectively equal to $3 \times 10^{-11} \mu_B$, $4 \times 10^{-11} \mu_B$, and $5 \times 10^{-11} \mu_B$. The effect from the standard weak interaction scattering in the same interval of $T$ is 0.17 events/kg day.

At the threshold energy in the range discussed here one should worry about the atomic binding effects for the electrons. However using the appropriate calculations for germanium we find that the correction due to the binding effects does not exceed 3% in the electron energy range (3 - 50) KeV.

Thus the estimates of the cosmic and reactor backgrounds for AS and PS spectrometers and the estimates of the effects of the electromagnetic and weak scattering of the reactor antineutrinos on electrons allow us to conclude the following:

- for measurements in the proximity of a reactor one should use a Ge spectrometer with active shielding, since this allows for a better suppression of the cosmic background; the background associated with the reactor activity does not exceed about 3% of the event rate due to NMM

- for the chosen interval of $T$ and the assumed values of NMM the number of scattering events due to the NMM ($N_{EM}$) exceeds that due to the standard weak scattering ($N_W$).
Table 2: Achievable 90% CL upper bounds on the NMM (in units of $10^{-11}\mu_B$) under various assumptions about the overall level of the background

| Time of experiment | 25 events/kg day | 15 events/kg day | 10 events/kg day |
|--------------------|-----------------|-----------------|-----------------|
| 1 year             | 5.2             | 4.6             | 4.2             |
| 2 years            | 4.4             | 3.9             | 3.5             |

For a threshold energy $T > 100\,Kev$ a reverse relation would hold, which would create a principal difficulty of extracting $N_{EM}$ from the sum $N_W + N_{EM}$. Although the weak scattering effect $N_W$ can be calculated, it contains an uncertainty due to the uncertainty in the energy spectrum of the reactor antineutrino$^{23,24}$. In the energy range $T = 100 - 1000\,KeV$ this uncertainty would amount to (3-7)%. In the case under consideration ($\mu_\nu > 3 \times 10^{-11}\mu_B$, $T = (3 - 50)\,KeV$) the sensitivity of the experiment is limited only by the statistics.

We present in Table 2 the estimates of the achievable sensitivity to the value of $\mu_\nu$ with a 2 kg detector with different assumptions about the resulting overall background level and for one and two years duration of the experiment. We assume that the measurements are taken with active reactor for 10 months in a year. One thus sees that it is realistic that the upper bound on $\mu_\nu$ can be lowered down to $(4 - 5)\times10^{-11}\mu_B$, using a low-background germanium spectrometer with the mass only about 2 kg.

6 Design, construction and parameters of a low-background $Ge - NaI(Tl)$ spectrometer for NMM measurement

An installation based on the principles described in the previous sections and on the experience of participation in low-background double beta decay experiments of $^{76}Ge$ is being constructed by our group in ITEP. This spectrometer is oriented towards measurements in proximity of a nuclear reactor with a maximal suppression of all components of the background.

The low-background spectrometer includes an array of 4 $Ge$ detectors with total mass above 2 kg inside a $NaI(Tl)$ active shielding. All 4 detectors are mounted in a common cryostat. All parts of the cryostat are manufactured from super pure materials: oxigen-free
copper, titanium, teflon. The shielding assembly has a form of a cylinder with a central hole. The dimensions of the NaI are: 450 mm in height, 400 mm in mean diameter with 135 mm diameter central hole. The assembly consists of 8 light-isolated sections in a common copper vessel. The ninth NaI crystal closes the central hole from the top (see Fig.1). As a reflector is used teflon film. The sections are monitored by 9 photomultipliers through bent optical guides. This allows to place the PMs, the voltage dividers and the cables outside the passive shielding and thus to significantly reduce the inherent background. The cryostat and the NaI assembly are surrounded by passive shielding consisting of 5 cm thick oxygen-free copper, 8 cm thick layer of borated polyethylene, 15 cm thick layer of lead and finally one more 8 cm thick layer of borated polyethylene. From the top the spectrometer is covered by an anti-cosmic scintillating plates with the size $120 \times 120 \times 4 \text{ cm}^3$. For protection against the radon a double hermetization and a nitrogen filling of the spectrometer can be engaged.

**Current status and results of preliminary tests of the spectrometer.**

The installation is located in a low-background laboratory in ITEP at the depth of 5 m.w.e. This allows to suppress the background from a nearby working accelerator and to significantly attenuate the strong interacting component of the cosmic background. At present the 4-crystal detector is being modified for reduction of the microphonic noise, the anti-cosmic outside scintillator is not installed and the radon protection is not engaged. The tests were performed with a one-crystal detector with the volume $106 \text{ cm}^3$. Therefore present results of background measurements are preliminary.

In the actual measurements at the depth of 20 m.w.e. the active shielding is expected to perform a dual function: to suppress the compton components in the background spectrum of the Ge detectors and for subtracting the cosmic induced events. In the tests a conventional logic was used to process the veto signals. The signal from the Ge detector was fed through a preamplifier and an amplifier to the analyser. Appropriately shaped signal from the NaI counters was fed to a summator-extender, after which the veto signals with duration from 10 $\mu$s to 200 $\mu$s was sent to the control input of the analyser. The threshold of the NaI counters for the gamma quanta was set in the interval 40 - 50 KeV, since according to previous measurements\(^{25}\) the gamma quanta of lower energy do not reach the counters and are absorbed in the outer inert layers. The efficiency of the adjustment of the system Ge detector - NaI counters in the veto regime was checked by using a $^{226}$Ra radioactive source, which was inserted between the cap of the Ge detector and the central NaI crystal. The results of the measurements were compared with the Monte Carlo simulation using the
| E(KeV) | 1   | 2   | 3   |
|--------|-----|-----|-----|
| 238.6 ($^{212}Pb$) | 1848 | —   | 0.18 |
| 295.2 ($^{214}Pb$)  | 890  | —   | 0.21 |
| 351.9 ($^{214}Pb$)  | 1352 | —   | 0.29 |
| 1460.8 ($^{40}K$)   | 2944 | —   | 0.12 |
| 1764.6 ($^{214}Bi$) | 327  | —   | 0.03 |
| 216.5 ($^{208}Ti$)  | 492  | —   | 0.02 |

| E(KeV) | 1   | 2   | 3   |
|--------|-----|-----|-----|
| 20 - 100 | 160 000 | 280 | 5.9 |
| 100 - 200 | 220 000 | 320 | 9.9 |
| 200 - 1500 | 18 000 | 68  | 1.5 |
| 1500 - 2700 | 800  | 6.7 | 0.10 |
| 2700 - 4000 | 6    | 4.8 | 0.02 |
| 4000 - 9000 | —    | 2.9 | 0.004|
| $10^4 - 5 \times 10^4$ | —    | 2.2 | 0.002|

Table 3: Results of background measurements. 1 - the detector is open, 2 - only the passive shielding engaged, 3 - both the passive and the active NaI shielding are used.

The discrepancy between the measured and the calculated background suppression factor does not exceed 15% over the energy range 50 - 2500 KeV, while the suppression factor itself reaches about 20 at certain energies. Further modelling using the GEANT 3.213 program revealed that the background suppression in the range 10 - 150 KeV can be improved by a factor of two or more by a modification of the detector construction.

**Background measurements**

The study of the background characteristics of the detector was performed by successively engaging the passive and the active NaI shielding.

The results of the measurements in the energy interval $20 - 5 \times 10^4$ KeV are summarized in the Table 3.

The total background count rate in the detector over the energy range 20 - 4000 KeV is 0.01 events/sec, which is already 3 times better than the best up-to-date figure for a low-background detector at a small depth ($15 \text{ m.w.e.}^{26}$). The total count rate of the NaI counters when fully covered by the passive shielding is 240 pulse/sec. The efficiency of the
suppression of the charged cosmic component in the energy range 10 - 50 MeV is 99.91%, which is also the best figure achieved so far. All the observed lines from the decay of the elements in the $U - Th$ sequence can be attributed to the presence in the installation of the radon 220 and 222.

An analysis of these data of the background measurements allows us to judge on the structure of the background at low energies. Of the 10 events/hour observed in the range 100 - 200 KeV 0.5 events/hour constitute the inherent radiation background of the spectrometer, 2.0 events/hour are contributed by the radon decay, 0.3 events/hour are attributed to the inefficiency of the veto system, finally, the dominant component of the background: 7 events/hour, comes from the secondary gamma quanta from the hadronic and muonic components of the cosmic background. These conclusions, derived from the observed spectrum, are also supported by the results of a simulation with the GEANT 3.213 program. The results of the measurements of the cosmogenic component of the background at the depth of 5 m.w.e. do not contradict the expected suppression at the depth of 20 m.w.e., since at these depths the rate of the neutron production $^{[21]}$ (and thus of the gamma production) by the cosmic rays differs by a factor of more than 20. The study of the structure of the background is ongoing and more complete and detailed results will be presented elsewhere.

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References

[1] R.Davis,B.T.Cleveland, and J.K.Rowley.Proc.of the 2-nd Int.Symp."Underground Physics 87",ed.Nauka,Moscow,1988.
K.Lande, *Results from the Homestake Neutrino Observatory*. Proc.of the 25th Int. Conf. on High Ener. Phys. Singapore. Ed. K.K.Phua, Y.Ymaguchi (Singapore,1991)p.667.
[2] G.A. Bazilevskaya, Yu.I. Stozhkov, and I.N. Charakhchyan, Pis’ma ZhETF 35 (1982) 273 [JETP Lett. 35 (1982) 340];
V.N. Gavrilin, Yu.S. Kopysov, and N.T. Makeev, Pis’ma ZhETF 35 (1982) 491 [JETP Lett. 35 (1982) 608].

[3] D.S. Oakley et al. ApJ. 437 (1994) L63.

[4] M.B. Voloshin, M.I. Vysotsky, and L.B. Okun, Yadern. Fiz. 44 (1986) 677; ZhETF 91 (1986) 754.

[5] B.W. Lee and R.E. Shrock, Phys.Rev.D16(1977)1444.

[6] M. Fukugita and T. Yanagita, Phys.Rev.Lett. 58 (1987) 1807.

[7] M.B. Voloshin, Yadern. Fiz., 48 (1988) 804.

[8] F. Reines, H.S. Gurr, and H.W. Sobel, Phys.Rev.Lett. 37 (1976) 315.

[9] G.S. Vidyakin, V.P. Martemyanov et al., Pis’ma v ZhETF, 55 (1991) 212.

[10] A.V. Derbin, L.A. Popeko et al., Pis’ma v ZhETF, 43 (1986); L.A. Popeko et al., Talk at the International School LEWI-90, Dubna, 1990.

[11] M. Fukugita. Neutrinos in cosmology and astrophysics: an introductory overview of theoretical aspects. Invited talk at Oji International Seminar on Elementary Processes in Dense Plasmas, Tomakomai, Japan, 27 Jun - 1 Jul 1994, Kyoto Univ. report YITP-K-1086, 1994.

[12] S.I. Blinnikov, ITEP Report ITEP-19-88, 1988, unpublished; S.I. Blinnikov and N.V. Dunina-Barkovskaya, Mon.Not.Roy.astron.Soc. 266 (1994) 289.

[13] R. Barbieri and R. Mohapatra, Phys.Rev.Lett. 61 (1988) 27.

[14] G. Raffelt, Phys.Rev.Lett. 64 (1990) 2856.

[15] M. Baldo-Ceoline, V. Barmin et al. Large Volume Liquid Xe-detector for Neutrino Magnetic Moment Measurement. ITEP report ITEP-35-92, 1992, unpublished.

[16] C. Broggini, V. Jorgens et al. A Gas Detector to Measure Antineutrino Magnetic Moment at a Nuclear Reactor. INFN-Gran Sasso report LNGS-91/03, 1991, unpublished.

[17] E. Garcia, J. Morales et al. Nucl. Phys.B (Proc.Suppl.) 28A (1992) 286.

[18] R.L. Brodzinski, F. T. Avignone et al. Nucl.Inst. and Meth. A292 (1990) 337.
[19] D.O.Caldwell, R.M.Eisberg et. al. Phys.Rev.Lett. 59 (1987) 419.

[20] S.Charalambus. Nucl.Phys. A166 (1971) 145.

[21] G.V. Gorshkov and V.A. Zyabkin, Atomnaya Energiya, 34 (1973) 210.

[22] V.I. Kopeikin, L.A. Mikaelyan et. al. Scattering of reactor antineutrino on electrons, Yadern. Fiz. in press.

[23] A.A.Hahn, K.Schreckenbach et. al. Phys.Lett. B218 (1989) 365.

[24] A.M. Bakalyarov, V.I. Kopeikin and L.A. Mikaelyan, Yadern. Fiz 59 (1996) 1225;
V.I. Kopeikin, L.A. Mikaelyan and V.V. Sinev, Yadern. Fiz. 60 (1997) 230.

[25] A.A. Vasenco, Yu.N. Vereshagin et.al. Installation for search of $2\beta$ decay based on Ge(Li) detector with $^{76}$Ge enrichment. Prib.Techn.Exp. 2 (1989) 56;
A.A.Vasenco, I.V.Kirpichnikov et. al. Mod.Phys.Lett.A, 5 (1990) 1299.
F.T.Avignone, A.S.Starostin et. al. Phys.Lett. B256 (1991) 559.

[26] F.El-Daoushy and R.Garcia-Tenorio, Nucl.Instr. and Meth. A356 (1995) 376;
G.Heusser. Nucl.Instr.and Meth. B58 (1991) 79.
Figure 1: The low background $Ge - NaI(Tl)$ spectrometer for NMM measurement. 1 - $Ge$ crystal, 2 - $NaI(Tl)$, 3 - oxigen-free copper, 4 - borated polyethylene, 5 - lead, 6 - anti-cosmic scintillator, 7 - moveable top shielding assembly.