Measuring of the ^{14}C low abundance in liquid scintillator samples using small volume detector in low background chamber at Baksan

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Abstract The scintillation detector was constructed to research ultralow concentrations of ^{14}C in liquid scintillator samples. The detector is placed in the low background Laboratory BNO INR RAS at a depth of 4900 m.w.e. Measurements of ^{14}C abundance was done for the samples of liquid scintillator on base of linear alkylbenzene. The detector counting rate was measured and the ratio $^{14}C/^{12}C$ was extracted from the experimental spectrum the LAB sample. The background model was developed and applied for ^{14}C abundance analysis. The value obtained is $^{14}C/^{12}C$ $(9.1 \pm 1.0) \times 10^{-16}$.

Keywords: Scintillator, radiocarbon, detector, radioactivity

1. Introduction

To study natural neutrino fluxes, a scintillation detector with a mass of at least 10 kt is required. To determine the component of the geo-neutrino flux from ^{40}K, the scintillator should be several orders of magnitude cleaner than that used to measure the flux of solar neutrinos [2]. In addition, it is necessary to get rid of the ^{14}C isotope contained in the scintillator, which prevents the study of solar neutrinos from the pp cycle and the geo-neutrino flux from ^{40}K.

A program for the search for a liquid scintillator with a reduced content of ^{14}C is proposed in the Institute for Nuclear Research. For this purpose, an installation with a small scintillation detector for the study of liquid scintillator samples was created in the underground low-background laboratory of the Baksan Neutrino Observatory of the Institute of Nuclear Research of the Russian Academy of Sciences. The possibility of using a small volume detector for measuring the concentrations of ^{14}C is indicated in [3], where a 1.5-liter detector was used.

The bench can also be used to study the background of a liquid scintillator loaded with neodymium (^{150}Nd), which is intended to be used to study double beta decay.

2. Low background detector

The detector is located in the underground low-background laboratory of the BNO of the Institute of Nuclear Research of the Russian Academy of Sciences [5] and is intended for measurements of ultralow concentrations of the ^{14}C isotope in samples of a liquid organic scintillator. The laboratory is located inside the mountain (3,700 m from the entrance to the tunnel), at a depth of 4900 m.w.e., where the muon flux is ~ 0.1 m^{-2} hr^{-1} [6]. To suppress the background from neutrons and gamma quanta of the surrounding rocks, the walls, floor and ceiling of the room where the scintillation detector is installed are consistently made of layers of polyethylene (25 cm), cadmium (1 mm) and lead (15 cm). The detector itself is placed in a box of plexiglass 14.5 × 14.5 × 120 cm^3 and is surrounded on all sides by a protection from extremely pure copper 15 cm thick and lead 10 cm thick. The principle diagram of the detector is shown in Fig. 1. The detector includes a quartz cell with a diameter of 100 mm and a length of 200 mm made of quartz glass 3 mm thick (a full volume of about 1.5 L) filled with a sample of liquid organic scintillator, two cylindrical optical fibers made of organic glass (PMMA) with a diameter of 90 mm and length 50 mm, and two low-background photomultipliers (PMT) ET9302B (3"). To increase the light collection, the quartz cell and lightguides are wrapped in a mirror reflective film of VM2000. For better optical contact between the quartz cell, light guides and PMT, a silicone lubricant was used. The sealed polyethylene cover surrounding the detector from the outside, served to protect against radon. From the internal volume, radon was removed by purging with nitrogen gas.

The conditions for measuring ultralow concentrations of radiocarbon make it necessary to use materials with a low content of radioactive impurities in the detector construction. Using a low-background semiconductor detector from HPGe high-purity germanium, measurements were made of the intensity of gamma quanta of a quartz cell and a photomultiplier ET9302B. According to the measurements, calculations were made of the content of radioactive impurities (Bq/kg) in the cell and the photomultiplier in Fig. 1.

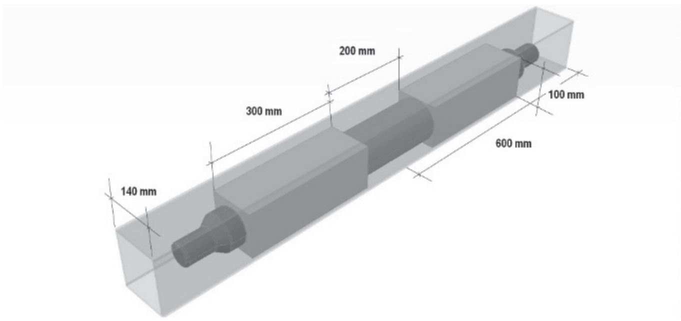

Fig1. *Low background detector scheme.*

To further improve the background characteristics of the scintillation detector, it is planned to use more low-background photomultipliers and optimize the protection of the cell from the radiation from the voltage dividers of the photomultiplier.

3. Scintillator samples

The linear alkyl benzene (LAB) obtained from China was studied. A sample of a liquid scintillator with an additive of 4 g/l PPO was prepared.

LAB is a mixture of hydrocarbons with the general formula C_nH_{2n-6}, density 0.856 g/l and a flash point of 143° C [8, 9]. LAB has the average formula $C_{17.73}H_{29.46}$ and is a mixture of four isomeric alkylbenzenes with the content: $C_{16}H_{26}$ – 0.125, $C_{17}H_{28}$ – 0.293, $C_{18}H_{30}$ – 0.315, C1 $C_{19}H_{32}$ – 0.267, each of which is present as a mixture of isomers of linear structure differing in the position of the phenyl residue in the hydrocarbon chain.

The light yield for a liquid scintillator based on a LAB (~ 8000 photons/MeV) and a coefficient of attenuation of a parallel light beam (15 m at a wavelength of light 420 nm) was obtained. The values obtained allow measurements in the low-energy (<50 keV) region of the beta-spectrum of radiocarbon.

For the measurements we used samples of a scintillator with a volume of 1360 ml, which are completely placed in a 1.5-liter cell.

4. Energy calibration

For the energy calibration of the detector, gamma-ray sources were used: ^{241}Am, ^{133}Ba, ^{137}Cs, ^{60}Co, ^{22}Na and ^{232}Th (^{208}Tl). The recoil energy of the recoil electron is also presented here for the backward scattering of the gamma quantum and the energy at the full absorption peak (FAP) for low-energy quanta. The energy for the maxima in the experimental distributions, which was used for calibration, is given.

5. Detector background

Solvent and copper protection of the detector passed special purification from radioactivity. Therefore, the equilibrium in the decay products of the natural radioactive chains of uranium and thorium is disrupted. If we assume that after the purification only the uranium and thorium isotopes remained, and the products of their decay were removed, then in 5 years, the thorium will again be in equilibrium with its products, and the uranium will have an equilibrium only of the ^{234}U isotope whose half-life is 2.45×10^5 years. Then the radon background will become independent, which can penetrate into the protection slots and fall into the sample of the scintillator during overflow. There is a background of ^{40}K, present in the glass and voltage divider faux. Cherenkov radiation from recoil electrons in the detector's optical fibers, caused by Compton scattering of energetic gamma quanta, can contribute.

Thus, we represent the background of the detector consisting of the following components:

1. Internal background from ^{238}U to ^{234}U,
2. The same external background, coming from the copper shield,
3. Internal background from ^{232}Th,
4. The same external background, coming from the copper shield,
5. Internal background from ^{222}Rn,
6. The same external background, coming from the copper shield,
7. External background of glass and faucet dividers from 40K,
8. The background of the Cherenkov light from the light guides together with the background of the pmt itself.

6. Determination of the contribution of ^{14}C decays to the number of scintillation cell events

The measurement of the ^{14}C content in the scintillator volume was carried out for 322.9 hours.

A digital oscilloscope National Instruments NI5105 was used to record the charge in the pulse from each photomultiplier. Trigger was the signal from one of the photomultiplier. The measurements were carried out in series, each of which was accompanied by two calibrations: one before the measurement, the other after.

The charge spectrum in the pulse of each series was transferred to the energy spectrum using its average calibration. Then the spectra were added with a weight equal to the measurement time.

The measured spectrum was fitted with simulated background spectra. The remaining part was assigned to the spectrum from ^{14}C.

At this stage, the scintillator was not blown with nitrogen to saturate it with carbon dioxide containing ^{14}C in a larger proportion. The figure shows the experimental spectrum, fitted with simulated backgrounds.

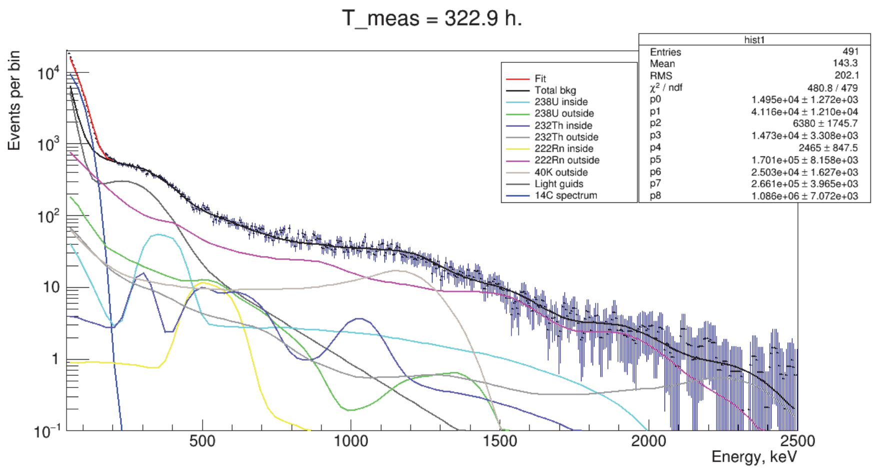

***Fig2**. Experimental spectrum from low background detector. Components of background are shown.*

Taking into account the volume of the scintillator (1360 ml), the value $^{14}C/^{12}C = (9 \pm 1) \times 10^{-16}$ for this LAB sample was obtained. Earlier, for the same sample, a value of $(5.5 \pm 1.0) \times 10^{-16}$ was obtained, and an even earlier measurement yielded a value $(3 \pm 1) \times 10^{-17}$. One can see the effect of saturation of the scintillator with carbon dioxide. Taking into account the limiting solubility of CO_2 1.18 of the scintillator volume [10], it is possible to estimate the ^{14}C content in the scintillator itself. In our case, we did not saturate the scintillator to the limit, so we take the amount of CO_2 in half of the limit, that is, 0.5 volume. We get here $^{14}C/^{12}C < 4 \times 10^{-16}$.

7. Conclusion

An installation for measuring its own background and the content of radiocarbon ^{14}C in samples of a liquid scintillator was created.

In our work, it is proposed to study samples of a scintillator with a base of a solvent obtained from various petroleum feedstocks to determine the effect of the deposit on the ^{14}C content. Solvents obtained from coal will also be investigated.

The background of the detector is analyzed in order to be able to further suppress it and lower the detector threshold for more confident separation of the ^{14}C beta spectrum. A model of the total detector background was created and successfully applied to the description of the experimental spectrum.

The setup will be used to measure the background of the scintillator with dissolved Nd for testing the methods of scintillator purification from natural radioactivity.

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