Ultra-low-background apparatus with germanium shielding

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(Submitted 10 July 1989)
Pis'ma Zh. Eksp. Teor. Fiz. **50**, No. 5, 222–225 (10 September 1989)

The results of radioactivity measurements in a thick-walled germanium cavity are discussed from the standpoint of designing an experiment to search for double β decay of germanium-76 which would have a sensitivity $T_{1/2} > 10^{25}$ yr.

In recent years the efforts of many laboratories around the world have been focused on solving the problem of arranging ultra-low-background conditions for HPGe detectors. A problem which has been taken up in these experiments, in addition to the main problem of searching for the neutrinoless double β decay of germanium-76, is that of achieving a background level which, like the background radiation, would be unsuppressible. The (v,e) scattering of solar neutrinos or a hypothetical interaction of the "dark matter of the universe" might play the role of this background.[1] The major difficulty in solving this problem is that of eliminating structural materials containing radioactive impurities from the immediate vicinity of the HPGe detector. In Refs. 2–6 the background was suppressed by a factor of 10^4–10^5 in comparison with that of an open detector at the earth's surface through a careful selection of materials based on measurements of their radioactivity and the use of passive shielding of zone-refined 400-year lead[2] or multiply distilled mercury. Similar results were achieved in Refs. 7–10, where the background was suppressed by placing the detector in active shielding with a NaI scintillator and also in an active Si(Li) cavity.[11]

In the present letter we are describing a new, low-background apparatus in which semiconducting germanium is used both as a structural material and as passive shielding for an HPGe detector. The technological procedure by which semiconducting germanium is synthesized, based on zone refining, presents a natural solution to the problem of the purity of the material, which is determined from its resistivity. For a germanium purity of 10 g/g, the resistivity is 47.5 Ω·cm corresponds to the technical requirements in the synthesis of polycrystalline germanium of type GPZ-1. The central part of the apparatus (Fig. 1) is a vacuum cryostat, in which there is a mercury cavity 390 mm in diameter and 360 mm high with a wall thickness of 80 mm, cooled to liquid nitrogen temperature. The GPZ-1 germanium, in the form of trapezoidal blocks each with a mass of 1.25 kg, fills the entire cavity in a close packing. Before the apparatus is assembled, the surfaces of the blocks are etched in a mixture of hydro-

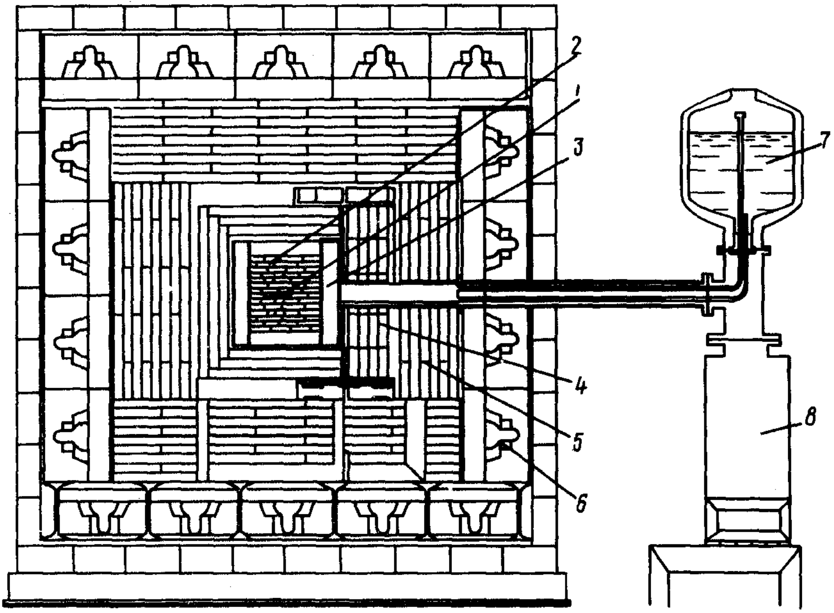

FIG. 1. Experimental layout. 1—HPGe detector; 2—germanium shielding; 3—mercury cavity; 4—copper shielding, 15 cm thick; 5—polyethylene shielding, 30 cm thick; 6—active scintillation shielding; 7—apparatus for cooling the cryostat with liquid nitrogen; 8—getter-ion pump.

fluoric and nitric acids and hydrogen peroxide. When the HPGe detector is transferred from a standard submersible cryostat manufactured by PGT to our germanium cavity, the surface of the detector is etched, and the central *P* contact, in the form of a steel spring, is replaced by a special spring germanium contact on which a layer of gold has been deposited. The shielding of the apparatus external with respect to the cryostat consists of a 15-cm layer of copper, a 2-mm layer of cadmium, and 30 cm of polyethylene. Above the apparatus there is a scintillation detector with an area of 2.5 m^2, which generates a veto signal for the germanium detector.

The measurements were carried out in an underground laboratory of the Institute of Nuclear Research, Academy of Sciences of the Ukrainian SSR, in a salt mine at Solotvin, at a depth of 436 m. The shielding against cosmic rays was 1000 meters water equivalent. The measurements were carried out in 24-h sessions with periodic calibrations. Figure 2 shows the background spectrum of an HPGe detector with a volume of 116 cm^3 in the germanium shielding, measured over 1004 h.

The spectrum is dominated by the annihilation peak (511.0 keV); the other struc-

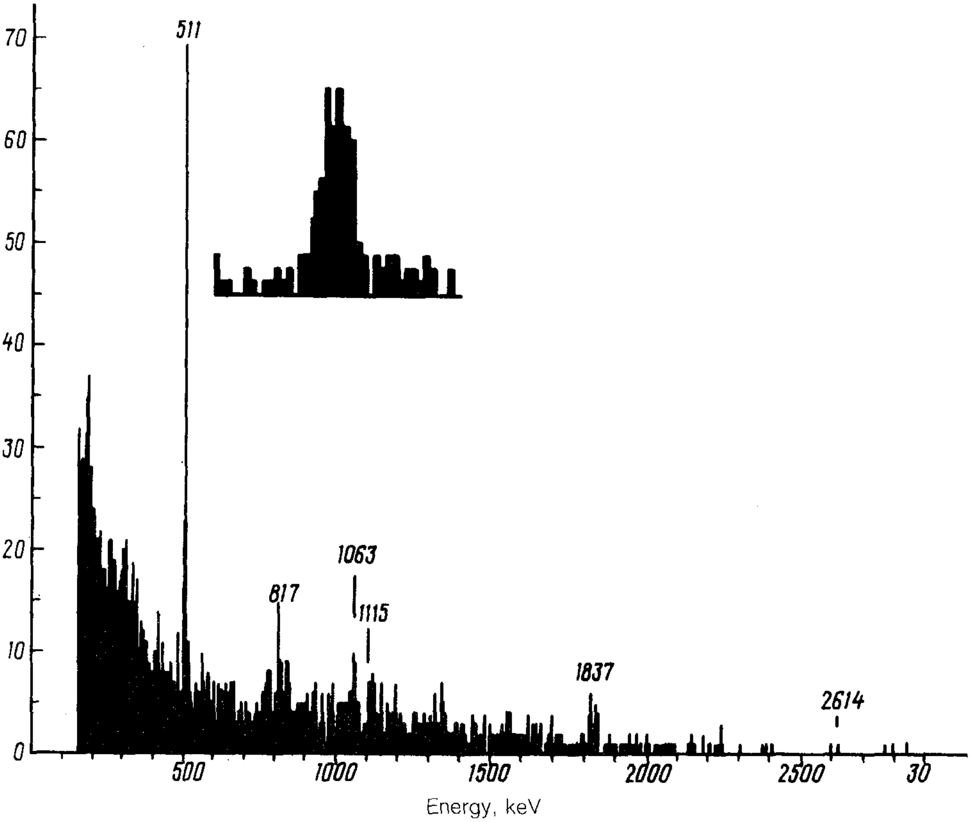

FIG. 2. Background spectrum of an HPGe detector, with a volume of 116 cm^3, in germanium shielding, measured over 1004 h (summation at 5 keV/channel).

tural features are not statistically significant. The average background level over the entire measurement time in the energy region of the neutrinoless double β decay of germanium-76 (2041 keV) was 1.5 ± 0.51 (keV·kg·yr)$^{-1}$, determined over a 100-keV interval. Over 1004 h, 11 events were detected. The most probable source of the radioactivity in the germanium cavity which led to the annihilation peak is the positron activity of gallium-68, which is produced as a result of the decay of germanium-68, which is present in the germanium shielding and which forms at the surface of the earth in the reaction 70Ge(n,3n)68Ge and has a half-life of 280 days.

From the observed decrease in the background during the measurement time, and from a comparison of the experimental spectrum with a spectrum calculated by the Monte Carlo method for the decay of 68Ge, we can conclude that 70% of the intensity in the background spectrum is due to the activity of 68Ge.

A comparison of our result with the data of Ref. 10, where a high sensitivity with respect to neutrinoless double β decay of germanium-76 was achieved, at a level of $T_{1/2} > 10^{24}$ yr, reveals that the apparatus with the germanium shielding has an important advantage over active scintillation shielding. In the first place, over the energy interval from 0.5 MeV to 1.5 MeV the maximum in the spectrum of the two-neutrino double β decay, with a half-life of 10^{21} yr, approaches the background level in our apparatus. Second, the absence of peaks at energies above 511.0 keV suggests that for a germanium-76 detector the background is lower by a factor of 2.3 as a result of the absence of Ge-70 and thus of Ge-68. Consequently, in measurements with an HPGe detector of 80% enrichment in our apparatus it is possible to obtain data on the shape of the spectrum of double β decay accompanied by the emission of two neutrinos if the half-life is 10^{21} yr. New data on the neutrinoless branch of the decay in the range 10^{25} yr in an experiment of this sort can be obtained only by constructing HPGe detectors from the separated isotope with a total mass of more than 10 kg.

We wish to thank the administration of the Institute of Nuclear Research, Academy of Sciences of the Ukrainian SSR, for the opportunity to carry out the measurements in the low-background Solotvin laboratory; Yu. G. Zdesenko, director of the Department of Lepton Physics, for assistance and useful discussions; M. S. Sheĭchuk for interest; and our colleagues at the Leningrad Institute of Nuclear Physics who participated in this study.

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Translated by Dave Parsons