Effect of Radon on SAGE Results

V. N. Gavrin, V. V. Gorbachev, and I. N. Mirmov

Institute for Nuclear Research, Russian Academy of Sciences, pr. Shestidesyatiletija Oktyabrya 7a, Moscow, 117312 Russia

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Abstract—A method for estimating the systematic uncertainty associated with radon in the SAGE experiment\textsuperscript{1)} aimed at observing the solar-neutrino flux is described. For the gallium target used in this experiment, the systematic uncertainty in the measured neutrino-capture rate of 75 SNU\textsuperscript{2)} is below 0.3 SNU. © 2002 MAIK “Nauka/Interperiodica”.

1. INTRODUCTION

Radon and products of its decay appear to be one of the main sources of background in experiments aimed at detecting solar neutrinos and double $\beta$ decay and at seeking dark matter and events of other rare processes. Radon, a gaseous element of the chain of $^{238}\text{U}$ and $^{226}\text{Ra}$ decays, can find its way into a detector, and its decays mimic sought events.

Since 1990, the SAGE Russian–American experiment has been measuring the rate of solar-neutrino capture in 50 t of liquid metal gallium. Neutrons interact with the target $^{71}\text{Ga}$ isotope via the reaction of inverse $\beta$ decay: $^{71}\text{Ga} (\nu, e^{-})^{71}\text{Ge}$. With the aid of a special chemical procedure, the product $^{71}\text{Ge}$ atoms are extracted from the target at the end of each exposure period (1–1.5 months); are converted into the gaseous state of GeH$_4$ (germane); and are placed into the proportional counter, where the decays of these atoms $[T_{1/2}(^{71}\text{Ge}) = 11.4 \text{ d}]$ are observed over a period of 5 to 6 months. A detailed description of the experiment, including the description of the chemical procedures for extracting germanium from the gallium target and procedures for counting $^{71}\text{Ge}$ decays and for analyzing the resulting data, is given in [1, 2].

We subdivide radon into external and internal portions according to the type of its effect. External radon is outside the counter in ambient air and is recorded in the counter owing primarily to $\gamma$ rays from $\beta$-decay elements. External radon is displaced from the environment of the counters by means of a blow through with evaporating liquid nitrogen. The residual activity of external radon is monitored by the active-shield system. It is constant in time; therefore, external radon affects only the background counting rate, increasing the statistical uncertainty of the measurements—there is no systematic bias of the measurement results in this case.

Internal radon, admixed to the counter gas during counter filling, has a totally different effect on measurements. Here, the detection efficiency is considerably higher than for external radon—almost all decays of radon and of elements of its decay chain are recorded. It is important to note that radon decays occur at the beginning of the exposure $[T_{1/2}(^{222}\text{Rn}) = 3.8 \text{ d}]$, increasing the measured number of $^{71}\text{Ge}$ decays. Thus, radon decays result in overestimating the measured flux of solar neutrinos. In this article, we assess this overestimation and indicate a possible way to reduce the systematic uncertainty caused by internal radon. The method used to estimate the systematic uncertainty is the following. Special features of the formation of pulses from the decays of radon and its daughter elements in the counter are determined on the basis of measurements. Further, the spectra of pulses for the decay of each radon-chain element are simulated. Taking into account the data obtained in solar-neutrino-run measurements and using the SAGE method for determining radon decays, we obtain the sought systematic uncertainty.

2. PROPORTIONAL COUNTERS AND COUNTING SYSTEM

Quartz cylindrical proportional counters are used in the SAGE experiment to detect $^{71}\text{Ge}$ decays. The

\textsuperscript{1)} The SAGE experiment is being performed with the aid of the gallium–germanium neutrino telescope (GGNT) at the underground laboratory of the Baksan Neutrino Observatory of the Institute for Nuclear Research (Russian Academy of Sciences) in the Republic of Kabardino-Balkaria (near Elbrus). This underground laboratory is located at a distance of 3.5 km from the entrance of the adit excavated into the Mount Andryuchi. The rock thickness provides shielding from cosmic muons corresponding to 4700 mwe.

\textsuperscript{2)} 1 SNU corresponds to one event of neutrino capture per second in a target that contains $10^{20}$ atoms.
3. MEASUREMENTS

Figure 1 displays the $^{222}$Rn decay chain. Its three elements decay through the emission of $\alpha$ particles, and two of them undergo $\beta$ decay. The chain ends in the $^{210}$Pb isotope, whose half-life ($T_{1/2} = 22.3$ yr) exceeds considerably the counting time of an individual run. The total lifetime of all chain elements, with the exception of the first one, is about 1 h.

In order to choose a correct model for describing processes occurring in the counter upon radon decay, measurements were performed with a large amount of radon (about 3200 atoms) placed into the counter gas. In processing the pulses, use was made of a special procedure that relies on the method of reconstruction of primary-ionization tracks [3, 4] and which makes it possible to study pulses in detail and to determine the pulse amplitude on the basis of the initial portion of the pulse [5]. In our case, the application of this method enabled us to extend the range of the energy measurement up to about 35 keV and to reveal some special features of the radon-decay spectra. Two spectra were obtained in the measurements: (1) the spectrum of events coinciding with signals from NaI (Fig. 2) and (2) the spectrum of events that do not coincide with signals from NaI (Fig. 3). The first is formed by $^{214}$Pb and $^{214}$Bi $\beta$ decays, which are accompanied by $\gamma$ radiation. Here, the measurements yield a descending spectrum without clear-cut structures. The spectrum of events that do not coincide with signals from NaI is more complicated: a peak with a resolution of about 41% is observed in