Experimental search for the decay of ^{58}Ni nuclei by the e^-e^+-conversion channel

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A two-crystal γ-ray spectrometer was used over a measurement time of 100 h. Limits are established on the half-life for ^{58}Ni decay by the e^-e^+-conversion channel: $T_{1/2}(0\nu+2\nu) > 7.0\times 10^{20}$ yr and $T_{1/2}(0\nu+2\nu) > 4.0\times 10^{20}$ yr for the 0^+–0^+ and 0^+–2^+ transitions, respectively.

The decay of ^{58}Ni nuclei in the e^-e^+-conversion channel was studied with an apparatus consisting of two NaI(Tl) detectors 15 cm in diameter and 15 cm high. The apparatus was installed in a low-background underground laboratory of the Baksan Neutrino Observatory, Institute of Nuclear Research, Russian Academy of Sciences, at a depth of 660 meters water equivalent.[1] Passive shielding consisting of 15 cm of lead, 6 cm of oxygen-free electrolytic copper, and 3 cm of tungsten suppressed the background from external γ rays.

Figure 1 shows the level scheme of the nuclear triplet ^{58}Ni–^{58}Co–^{58}Fe along with a possible scheme for the decay of ^{58}Ni in the e^-e^+-conversion channel to the 0^+ and 2^+ levels of the daughter nucleus. This transition, involving e^+ emission, has certain advantages from the experimental standpoint: The positron which is emitted creates two strictly correlated annihilation γ rays. In the case of the 0^+–2^+ transition to the first excited level of the ^{58}Fe daughter nucleus, two annihilation γ's are produced, each with an energy of 511 keV; one γ ray with 811 keV is also produced. The use of multidimensional $(E_\gamma\times E_\gamma)$ spectra in this case provides further advantages in the detection of cascade γ rays, and it improves the sensitivity of the experiment.[1]

The Ni test sample (the natural abundance of ^{58}Ni is 68.3%[2]), in which the number of ^{58}Ni nuclei was 1.3×10^{25}, was in the form of thin metal plates. It was placed between two NaI(Tl) crystals. Each NaI(Tl) detector had an energy resolution $\sim 9\%$ for a ^{137}Cs source ($E_\gamma=662$ keV). For an energy calibration and a calculation of the detection efficiencies we used ^{22}Na, ^{60}Co, and ^{207}Bi point γ sources, along with distributed ^{40}K, ^{232}Th, and ^{238}U sources. Copper plates ~ 1 cm thick were used as a control background sample. The signals from the two NaI(Tl) detectors were converted into a multidimensional spectrum with the help of an NTA-4096 multichannel pulse-height analyzer. The data from the analyzer were stored on magnetic tape; further analysis of the spectra was carried out off line.

Figure 2 shows an experimental multidimensional $(E_\gamma\times E_\gamma\times N)$ spectrum for the ^{58}Ni test sample from the two NaI(Tl) detectors. This spectrum was built up over 100 h. The energy evolution in the detectors is plotted along the X and Y axes, and the number of events along the Z axis. In the energy region 511 keV$\times$511 keV we have

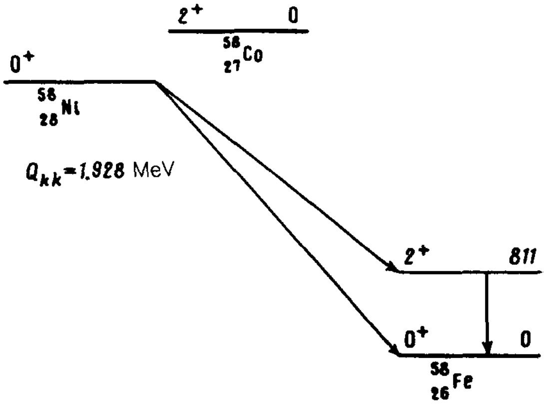

FIG. 1. Level scheme of the nuclear triplet ^{58}Ni–^{58}Co–^{58}Fe.

singled out a part of the matrix in which we would expect to detect the two annihilation γ rays from the possible decay of ^{58}Ni by e^-e^+ conversion. The count rate for ^{58}Ni in this region is 0.70 ± 0.08 event/h, while the background count rate is 0.63 ± 0.08 event/h. Since the calculated efficiency of the detection of annihilation γ rays is $\sim 7\%$, we can set a lower limit on the half-life for ^{58}Ni decay in the e^-e^+- conversion channel for the transition to the 0^+ ground level of the daughter nucleus: $T_{1/2}(0\nu + 2\nu) > 7.0 \times 10^{20}$ yr.

For the transition to the 2^+ first excited level of the daughter nucleus, we analyzed the following regions of the multidimensional spectrum: 511 keV$\times$511 keV, 511 keV$\times$811 keV (there are two such regions), and 511 keV$\times$1322 keV (again, there are two such regions). The overall efficiency of the γ-ray detection for the data in these five regions is $\sim 6\%$. The count rate for the ^{58}Ni sample and that for the background are 1.66 ± 0.13 events/h and 1.56 ± 0.12 events/h, respectively. As a result, we find a limit on the half life of the decay of ^{58}Ni in the e^-e^+-conversion channel for the case of the transition to the 2^+ first excited level of the ^{58}Fe daughter nucleus:

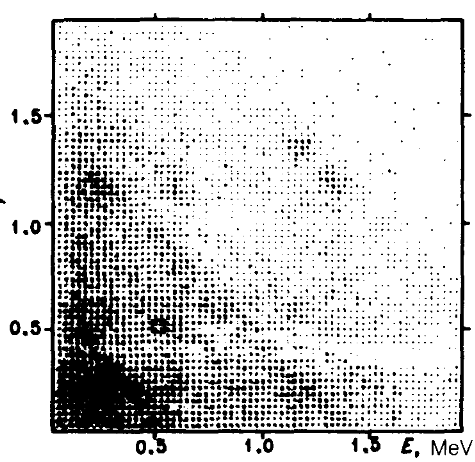

FIG. 2. Experimental multidimensional spectrum for the ^{58}Ni sample from the two NaI(Tl) detectors, built up over 100 h.

$T_{1/2}(0\nu+2\nu) > 4.0\times 10^{20}$ yr. These results correspond to a confidence limit of 68%. The limits found on the half-life for the decay of ^{58}Ni in the e^-e^+-conversion channel are about ten times the results reported in Ref. 3.

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