Performance of the n-type HPGe Detector used for the Determination of the ^{60}Fe Half-Life

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We determined the half-life of the radioactive isotope ^{60}Fe using high precision measurements of the mass and activity of a sample containing over 10^{15} ^{60}Fe atoms [1]. This new measurement for the lifetime of ^{60}Fe has significant implications for interpretations of Galactic nucleosynthesis, for determinations of formation time scales of solids in the early solar system, and for the interpretation of live-^{60}Fe measurements from supernova-ejecta deposits on Earth.

Following chemical extraction from a copper beamdump, the ^{60}Fe sample was investigated through multi-collector inductively-coupled plasma mass spectrometry. This technique allowed for a measurement of the ^{60}Fe/Fe ratio as well as the total Fe content. The sample's activity was measured with a n–type coaxial High–Purity Germanium (HPGe) detector in a low background underground laboratory (first measurements see [2]). The long time stability of this detector in terms of peak centroid and peak efficiency is the topic of this report.

1. Detector System

The measurements of the activity were performed in MLL's shallow underground laboratory with a shielding of 15 mwe (meter water equivalent) to reduce cosmic ray induced background [3]. The system consists of a HPGe crystal with an active volume of 113 cm^3 and a 1.06 mm thin entrance window made of carbon fiber. The detector is housed in a lead shielding (150 mm thick). Its inner layer consists of 50 mm of high purity lead with a specific ^{210}Pb activity of less than 27 mBq [4]. Additionally the sample chamber is surrounded with a 5 mm copper lining and flushed with the boil-off nitrogen of the dewar. To allow reproducible positioning of the samples they were put in a custom made plastic holder system. To avoid possible problems with a too close geometry, 233 days after the separation the sample was moved to a distance of 10 cm from the detector end cap. This report deals with the performance at that position.

1.1 Gamma Lines of Interest

The radioisotope ^{60}Fe decays via the metastable ^{60}Co^m ($T_{1/2}$ = 10.47 min) to ^{60}Co ($T_{1/2}$ = 1925.28 d). For the activity measurement the grow-in of the two prominent γ-ray lines of 1.17 MeV and 1.33 MeV of ^{60}Co was routinely monitored.

1.2 Analyzing Software

The spectra were recorded and all fits were performed with the GASPAN [5] gamma spectrum analysis program. The parameterizations used in this code follow the approach by Phillips and Marlow [6]. The parameters for the fits were a Gaussian with consideration of background tails from γ-rays and a background polynomial. Considering the residual of the fits this provided an adequate description of the line shape and content at both energies, see Fig. 1.

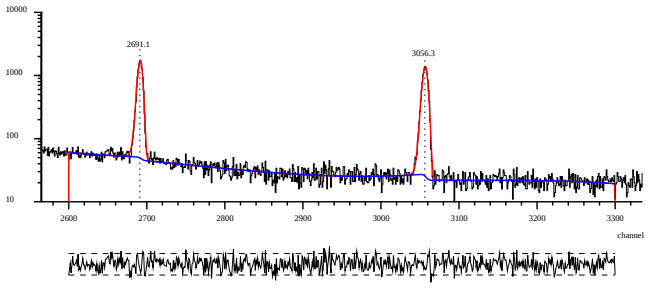

Fig. 1: Pulse height spectrum of the master sample measured with the HPGe detector. The fit was performed with GASPAN. The two peaks correspond to the γ-lines of 1.17 MeV and 1.33 MeV of ^{60}Co.

1.3 Background Rate

The background rate in the region of the ^{60}Co-γ-lines was measured to be less than 0.5 mBq. This ratio has been also confirmed at the end of the experiment. The activity from ^{40}K is very low likewise for other natual background lines, therefore no Compton edge is observed in the spectrum.

1.4 Properties of the Measured Samples

In contrast to the measurement by Kutschera *et al.* [7] we used a relative approach for the determination of the activity. This is realized via a measurement of the relative emission rate for the two γ-rays in comparison with a similar source of known activity. This approach should minimize systematic uncertainties. The sample was 5 mL of 0.1 M HCl solution containing the iron isotopes. This liquid was put into a glass vial and sealed [1]. For energy and relative efficiency determination a calibration standard with the same geometry as the iron sample was used. Its initial activity was 102.0±1.5 Bq (1 σ) in 5 mL liquid solution[2]. This activity is in the range of the expected saturation activity of the iron sample. The chemical form was also a weak acid. As a cross check a ^{60}Co point source[3] was used in the beginning (534 Bq) and at the end (358 Bq).

[1] The type of the glass vial was SU 860065 with the septum #854996 (silicon with a PTFE layer); it was obtained from Sigma-Aldrich Chemie GmbH, D-82024 Taufkirchen, Germany.

[2] Calibration certificate from AEA Technology QSA GmbH, 38110 Braunschweig, Germany, with calibration label 015367 DKD-K-06501 05-06; date of calibration June 1st, 2005.

[3] certificate 418-81 from PTB, Braunschweig, Germany, activity: 6 540 Bq (±1% at 99% confidence intervall); reference date: 01.01.1987

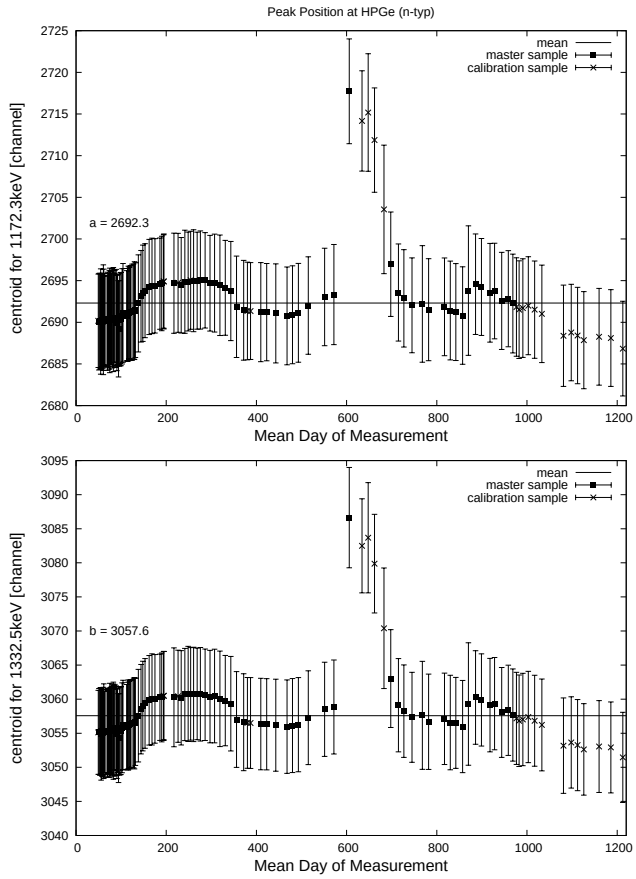

Fig. 2: Centroid of peaks in the pulse height spectrum for the master sample and the calibration standard as a function of time. The mean of the 1.17 MeV and 1.33 MeV γ-ray lines is also shown with its value a or b with a horizontal line. The system was very stable over the period of the measurement with the exception of the shift at around 600 days, see text.

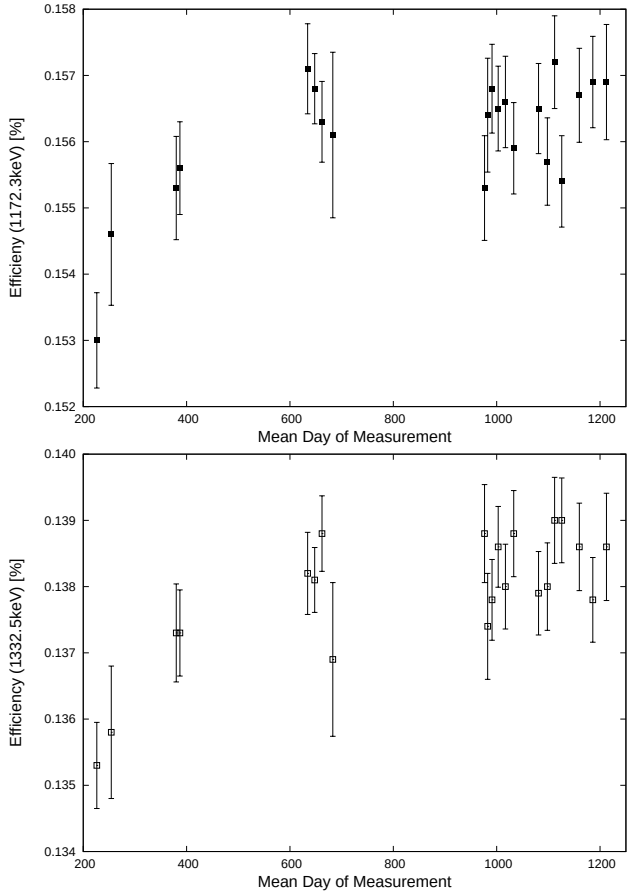

Fig. 3: Efficiency of the detector for the two γ-lines. For data analysis the average between two calibration periods was used.

2. Data Taking

Most of the individual runs were performed for 10^6 s, resulting in more than 10^4 counts in the respective peak areas. The measurement of the iron sample was interrupted for calibration runs with a long calibration run to confirm the detector performance at the end.

2.1 Photo Peak Centroid Stability

The result of the analysis of the pulse height spectrum for the centroid with its width is shown in Fig. 2. The position of the centroid was very stable even after a high voltage shutdown due to a power outage after about 500 days. We checked a possible change after 600 days. Hence, the measurement of the iron sample was stopped and the position of the centroid checked with the standard. A jump was detected for both lines referring to a shift in the electronics. After some days the centroid returned to the position from before and the data taking for the iron sample was continued. Since the fits were done with free peak position and width this jump has no influence on the data analysis. In total the system was remarkably stable.

2.2 Photo Peak Efficiency

Since the detector mass of about 600 g is not very large and the distance for the sample is 10 cm the absolute efficiency for the two γ-lines is small. But the large distance prevents problems due to a high count rate or a misalignment of the sample. For data analysis the average value of the standard runs before and after the master sample was used. As can be seen in Fig. 3 the system was very stable. This means also that the sample holder construction allowed a reproducible sample exchange. There is no sign of any loss of material over this long counting period. The variation of the efficiency is smaller than the uncertainty of the standard. Therefore a reduction in the uncertainty could be achieved with a more precise calibration standard in the same geometry. The point source could not put as accurately as the glass vial, nevertheless the deviation for the efficiency was less than 4 %. Therefore our approach to determine a ratio of activities should be very reliable.

References

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