Astroparticle Physics 46 (2013) 23–28

Contents lists available at SciVerse ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropart

Experimental test of the time stability of the half-life of alpha-decay ^{214}Po nuclei

E.N. Alexeyev [a], V.V. Alekseenko [a], Ju.M. Gavriljuk [a], A.M. Gangapshev [a], A.M. Gezhaev [a], V.V. Kazalov [a], V.V. Kuzminov [a], S.I. Panasenko [b], S.S. Ratkevich [b,*], S.P. Yakimenko [a]

[a] Baksan Neutrino Observatory, Institute for Nuclear Research RAS, 361609, Russia
[b] V.N. Karazin Kharkiv National University, 61022, Ukraine

ARTICLE INFO

Article history:
Received 15 June 2012
Received in revised form 15 March 2013
Accepted 23 April 2013
Available online 9 May 2013

Keywords:
Nuclear Decay Lifetimes
Nuclear Decay Fluctuations
Alpha decays
Beta decays

ABSTRACT

A method and results of an experimental test of the time stability of the half-life of alpha-decay ^{214}Po nuclei are presented. Two underground installations aimed at monitoring the time stability have been constructed. Time of measurement exceeds 1038 days for one set up and 562 days for the other. It was found that the amplitude of a possible annual variation of ^{214}Po half-life does not exceed 0.33% (90% C.L.) of the mean value. The limit on the deviation of the decay curve from exponent at $0.034 \times T_{1/2} < t < 0.1 \times T_{1/2}$ range has been found.

1. Introduction

A number of investigations aimed to check absolute stability of half-life of different radioactive isotopes and to search for possible time variations of the half-life constants under action of known and possible unknown natural factors has been carried out during last years.

It was shown in paper [1] that after many years of investigations with scintillation and semi-conductor α-ray detectors, a conclusion was made about changes of rate of radioactive elements' β-decay with 24 h and 27 days periodicities.

The data of many years measurement's of decay rates data for the ^{32}Si (β-decay) (Brookhaven National Laboratory, USA, 1982–1986 years) and for the ^{226}Ra (α- and β-decays) (Physikalisch-Technische-Bundesanstalt, Germany, 1983–1998 years) were analyzed in papers [2–6]. Decay rate variations with a one year period and maximum amplitude of ~0.15% in January–February were found in both data sets. The authors considered an assumed seasonal variations of the detector systems characteristics and/or the direct annual modulation of the count rate being caused by some unknown factor depending on the Sun–Earth distance as possible causes of such count rate variations.

The weak point of the count rate long time monitor experiments is a possible influence of meteorological, climatic and geophysical factors on the count rate of a source-detector pair. This shortcoming could be practically totally avoided in measurements based on a direct registration of a nuclear life time between birth and decay. Such a method allows us to answer the question of possible change with time of a just nuclear decay constant.

Besides that a direct registration of nuclear lifetime allows to study the exponentially decay low. Some theoretical models [7,8] predicted that the decay curve does not exactly follow an exponential law in the short- and long-time regions in particular due to the so called quantum Zeno effect [9–12]. Experimentally Zeno effect was proved [13] in repeatedly measured two-level system undergoing Rabi transitions, but not observed in spontaneous decays. Very important condition for to measure possible deviations from an exponential law that the investigated nuclei could have the same age.

2. Overview of the experimental measurements

A primary task in this work was to investigate constancy of a half-life τ ($\tau \equiv T_{1/2}$) of ^{214}Po during several years. ^{214}Po decays with 164.3 ± 2.0 μs half-life [14] by emitting 7.687 MeV α-particle. This isotope appears mainly in the exited state (~ 87%) in the ^{214}Bi β-decay. The half-lives of the exited levels does not exceed 0.2 ps [15] and they discharge instantly with regard to the scale of the ^{214}Po half-life. Energies of the most intensive γ-lines are equal to 609.3 keV (46.1% per decay), 1120 keV (15.0%) and 1765 keV (15.9%). So, the β-particle and γ-quantum emitted at the moment

* Corresponding author. Tel.: +7 4991353135; fax: +7 4991352268.
E-mail addresses: alexeyev@ms1.inr.ac.ru (E.N. Alexeyev), ratkevich@mail.univer.kharkov.ua, ssratk@gmail.com (S.S. Ratkevich).

0927-6505/$ - see front matter
http://dx.doi.org/10.1016/j.astropartphys.2013.04.005

of the birth of ^{214}Po nuclear (start) and the α-particle is emitted at the decay moment (stop). Measurement of "start-stop" time intervals allows one to construct decay curve and to determine the half-life from its shape.

^{214}Bi isotope is an intermediate daughter product in the ^{238}U series. It gives almost all γ-activity of the series. This isotope could be produced with a constant velocity if an intermediate isotope ^{226}Ra ($T_{1/2} = 1600$ y) of the ^{238}U series will be used as a source. A time of an equilibrium reached in a partial ^{226}Ra–^{214}Bi series equals to $\sim$ 20 days and is determined by the longest half-life isotope, ^{222}Rn (3.82 days). A ^{214}Bi decay rate does not change after this time if a source is hermetically sealed to prevent an escape of radon.

Two test sources with ^{226}Ra activity of $\sim$ 90 Bq and $\sim$ 20 Bq were prepared in the V.G. Khlopin Radium Institute (St. Petersburg, Russia) in March, 2008.

A thin transparent radium spot is deposited in the center of a polished plastic scintillator (PS) disc of 18 mm diameter and 0.8 mm thickness. Then, the PS disc was covered by a similar disc hermetically glued on periphery (2.5 mm width). A PC registers all charged particles generated in the decay series. A PS light yield for an α-particle absorption is $\sim$0.1 of that for the electron of the same energy. Due to this fact α-spectra mix with β-spectra if a scintillator is thick enough to absorb completely the energy of an electron. To prevent this effect and separate these spectra the scintillator discs were made thin enough so that electrons lose only part of their energy.

Two setups named TAU-1 and TAU-2 were made to measure the radiations of these sources. A schematic sectional view of the TAU-1 with the electronics is shown in Fig. 1. The detector D1 contains the photomultiplier (FEU-85) which views the source disc through a plastic light guide.

A Teflon reflector is placed under the source to improve light collection. The whole assembly is packed in a stainless steel box. The detector D1 is placed on the end face of the scintillation detector D2 with low background NaI (Tl) crystal of 80 mm diameter and 160 mm length. The crystal has a stainless still cover and a quartz entrance window. The crystal with photomultiplier (FEU-110) is placed in a closed copper cup. The two detectors are mounted vertically in a low background shield made from Pb (10 cm) + Fe (15 cm) + W (3 cm). The activities of ^{40}K, ^{232}Th and ^{238}U in the used materials were measured with Ge gamma spectrometer. The values are shown on the Table 1. The shield reduced the background in the D2 detector in the energy region of 0.3–3.0 MeV by $\sim$1000 times up to count rate of $\sim$0.3 s^{-1} in comparison with the unshielded one. The TAU-1 is located in the underground laboratory "KAPRIZ" of the Baksan Neutrino Observatory of INR RAS at 1000 m of water equivalent depth. The cosmic ray background is decreased by $\sim$10^4 times due to the rock thickness in comparison with the ground surface one. Walls of the laboratory are covered by a low background concrete thus decreasing by $\sim$8 times the γ-ray background from the rock natural radioactivity.

Signals from the photomultipliers are read by charge sensitive preamplifiers (CSA) and fed to two inputs of a digitizer (digital oscilloscope – DO) LA-n20-12PCI connected to a personal computer (PC). Pulses are digitized with 6.25 MHz frequency. The DO pulse recording starts by a signal from the D2 which registered γ-quanta of ^{214}Bi-decays. A D2 signal opens a record of a sequence with 655.36 μs total duration where first 81.92 μs time is a "pre-history" and the last 573.44 μs is a "history" with time bin = 0.16 μs. Duration of a "history" exceeds the three ^{214}Po half-lives.

A PS disc source in the TAU-2 installation is fixed at the end of an air light guide having a smooth wall made of VM-2000 light reflecting film. The light guide is put into 0.8 mm thick stainless steel rectangular frame with inner dimensions of 150 × 23 × 9 mm. An open butt-end of the frame is welded into a bottom of cylindrical stainless still body of 45 mm diameter and 165 mm length where the photomultiplier is placed. Two scintillation detectors (D2a and D2b) made of large NaI (Tl) crystals (150 × 150 mm) are used for a registration of the γ-quanta. Each crystal has a stainless steel cover and a quartz entrance window. Photomultipliers (FEU-49) are used for the light registration. The D1 are installed into a gap between D2a and D2b. A scheme of pulse registration in the TAU-2 is similar to the one of TAU-1 but signals from D1a and D2b are summed in additional summator. The TAU-2 is located in the low background room in the deepest underground laboratory DULB-4900 of the BNO INR RAS at the 4900 m of water equivalent depth. The cosmic ray background is decreased by $\sim$ 10^7 times by the rock thickness in comparison with the ground surface one. The room walls are made of polyethylene (25 cm) + Cd (0.1 cm) + Pb (15 cm). The detectors are surrounded

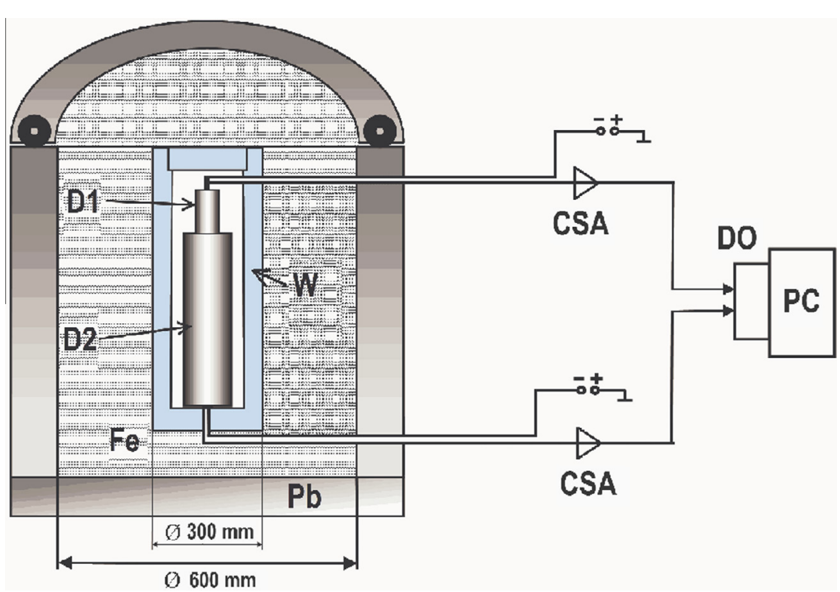

Fig. 1. Schematic cross-sectional view of TAU-1 setup and electronics block diagram.