Determination of Th-chain contamination in a high sensitivity detector

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There is a great need for an extremely high sensitive radiation detector in the field of nuclear physics, particle physics and astro physics. In the case of dark matter search, the energy spectrum due to the interaction of WIMPs (Weakly Interacting Massive Particles) is expected to be less than several tens of keV. The event rate of WIMPs-nucleus interaction is expected to be less than 1/kg/day [1]. In the case of double beta decay, the energies of electrons extends to a few MeV. The event rate of neutrinoless double beta decay is expected to be less than a few events per year [2]. Consequently, the extremely low background measurement is needed.

The sources of the background are divided into two types, internal source and external source. The internal source is contained in the sensitive volume a detector, and the external source is contained in the surrounding materials of the detector. Most background due to the external source can be reduced by the passive shields (e.g. OFHC copper and lead for γ, Cd sheet for neutrons) and active shields (anti-Compton measurement). However, the internal background radiations are difficult to reduce. Especially the U-chain and Th-chain nuclei are main origin of the internal background source. They suffer the sensitivity in the quite wide range of the energy from few keV to several MeV. Thus, a technique to identify the location and the condensation of the contamination is quite important to create a high sensitive detector.

We applied the $\alpha - \alpha$ time-correlated analysis to measure the extremely small concentration of Th-chain in a NaI(Tl) scintillator crystal. In the present work, we measured the concentration of Th-chain nuclei in a NaI(Tl) crystal with the dimension of $5.72 \times 5.72 \times 10.16\text{cm}^3$. The NaI(Tl) crystal was covered with PTFE sheet and an OFHC (Oxygen Free High Conductive) copper housing. The NaI detector was installed into an air-tight container made of 1cm thick OFHC copper. High purity Rn-free nitrogen gas was flushed into the air-tight container. The air-tight container was covered with 10cm thick old lead bricks which shielded against gamma rays. The whole system was installed into the third experimental room in Oto Cosmo Observatory to avoid the comic ray background.

Since the dead time of the data acquisition system was less than a few milliseconds, the two alpha rays from ^{220}Rn and ^{216}Po were acquired as if they were two individual events. In order to measure the time lag between two alpha events, additional timing information was measured. A 10kHz clock generator was fed into a scaler. The scaler was cleared immediately after the data of the event was acquired, thus the value of the scaler corresponded to the time interval of the two events. The time interval distribution was analyzed to calculate the half life of the sequential decays.

The energy threshold for off-line analysis was determined by the response of α ray from

^{220}Rn. Finally we successfully obtained the prominent peaks of the alpha rays of ^{220}Rn and ^{216}Po. The energy spectrum of the second event which corresponds to the decay of ^{216}Po is shown in Figure 1.

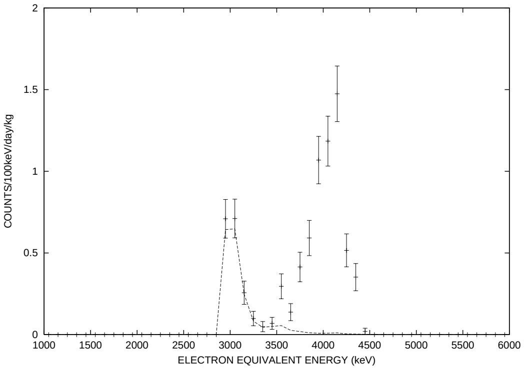

Figure 1: The energy spectrum of the second event of two successive decay. The contribution of the chance coincidence is shown by the solid line.

In order to confirm that the peaks were due to the decays of $^{220}\mathrm{Rn}\rightarrow{}^{216}\mathrm{Po}\rightarrow{}^{212}\mathrm{Pb}$, we plotted the time difference of the two events and calculated the corresponding half life. The fitted half life was 143±17ms, which was consistent with the half life of ^{216}Po.

The $\alpha-$detection efficiency ϵ was estimated the following way. The intrinsic detection efficiency of the alpha ray was unity because the Th-chain nuclei are contained in the NaI(Tl) crystal. Thus the efficiency ϵ is equal to the probability that the ^{216}Po decays between 1.3ms and 1000ms after the first event. The efficiency was calculated as $\epsilon = 0.985$. Using the peak yield of α rays with the live time of 41.7day×1.22kg, the radioactivity of ^{216}Po in the NaI(Tl) crystal was $70 \pm 4\mu$Bq/kg.

We determined the radioactivity of Th-chain contamination in a NaI crystal. The decay chain between ^{220}Rn and ^{212}Pb was clearly extracted by the off-line analysis. The selectivity for this analysis is high because both ^{220}Rn and ^{216}Po emit high energy alpha rays.

The measured radioactivity $dN/dt = 70\mu$Bq/kg corresponds to 17ppt for ^{232}Th, assuming the secular equivalence of radioactivity. One should pay attention to applying this analysis for a newly developed crystals. The Th chain cannot be in secular equilibrium just after its development, which was pointed out by Barton et al.[3].

We have shown that the time correlation analysis has a great advantage to determine the concentration of Th-chain nuclei. The sensitivity reaches a few μBq/kg with an uncertainty of less than 10% by the measurement with the live time of about 10kg·day.

References

[1] J.R.Primack,D.Seckel and B.Sadoulet: Ann. Rev. Nucl. Part. Sci. **38** (1988) 751; P.F.Smith,J.D.Lewin: Phys. Rep. **187** (1988) 203.

[2] W. C. Haxton and G. J. Stephenson Jr. , Prog. Part. Nucl. Phys. **12** (1984) 409; M. Doi, T. Kotani and E. Takasugi, Suppl. Prog. Theor. Phys. **83** (1985) 1; H. Ejiri, Nucl. Phys. **B** (Proc. Suppl.)**91** (2001) 255 and references therein.

[3] J.C.Barton and J.A.Edington, Nucl. Instr. Meth. **443** (2000) 277.