The improvement of high purity NaI(Tl) scintillator for Dark Matter Search

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A NaI(Tl) scintillator was applied to serch for the WIMPs (Weakly Interacting Massive Particles) by WIMPs-nucleus direct interaction[1]. The advantages of using the NaI scintillater for dark matter search were shown as follows. Both ^{127}I and ^{22}Na have the large cross-section for WIMPs and the ^{127}I nucleus is expected to be excited by inelastic scattering which is followed by 57.6keV γ ray [2][3][4]. Since the NaI detector works in the normal temperature, we can enlarge the detector volume with low cost to obtain the good statistical accuracy.

Expected event rate of WIMPs-nucleus interaction is 10^{-2}cpd/kg/keV at the energy threshold of 2keV in the electron equivalent energy[7]. To detect the WIMPs signal, the radioactivity in the NaI crystal should be less than 1μBq/kg of both U-chain and Th-chain.

The best way to determine the concentration of U-chain is the β-α delayed coincidence method[5]. The β rays from ^{214}Bi are observed as a prompt signal and the α rays from ^{214}Po are observed as a delayed signal by performing this method. Cosmic rays were the main background in the energy region where the peak of α rays was measured in an overground laboratory. In order to reduce the background due to cosmic rays, the measurement was performed at the underground laboratory; Oto Cosmo Observatory, RCNP Osaka University. The cosmic ray flux was about 4×10^{-7}cm^{-2}sec^{-1} which was five order of magnitude smaller than the one in overground laboratotory[6]. The NaI(Tl) scintillator whose dimension was 5.08cm$\times$5.08cm ϕ covered with 6cm thick Oxygen-Free-High-Conductive copper(OFHC) bricks and 10cm thick old lead bricks.

A peak yield of ^{214}Po was 14 events for the live time of the 0.37kg$\times$35.1days. The radioactivity of ^{214}Po in the crystal was calculated as 12.7$\pm$3.4μBq/kg. In the case that the U-chain is in the secular radioactive equilibrium, it corresponds to 1.02$\pm$0.26ppt of the concentration of ^{238}U. Comparing our improved scintillator with a previous scintillator which was used for dark matter search, we found that the concentration of ^{214}Po was successfully improved one order of magnitude(See Figure 1).

The peaks of α rays and γ rays overlapped each other in the singles energy spectrum from 2MeV to 3MeV. It was difficult to determine the concentration of these nuclei from the singles spectrum. To know the yield of α rays is useful for investigating the radioactive impurity in a detector, since the α ray are observed only in the case that the source is contained in a detector and show a monoenergy peak.

The pulse shape discrimination (PSD) method was applied with a quite simple circuit to obtain the precise yield of the α rays. We succeeded in discriminating α rays from γ rays by the surprisingly simple circuit. The two dimensional plot is shown in Figure 2. Vertical axis corresponds to the electric charge which was integrated partially, horizontal axis corresponds

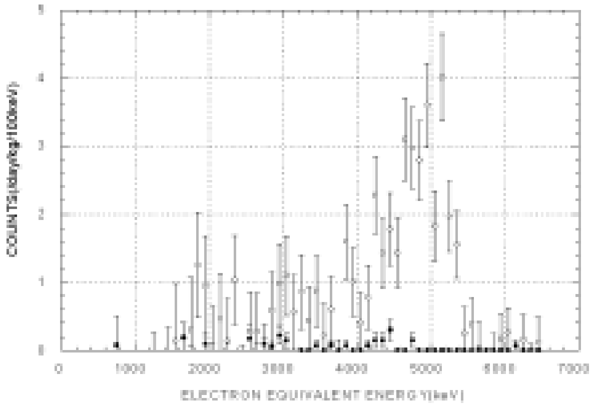

Figure 1: The delayed α rays energy spectra. Opened circles shows the energy spectrum obtained by previous crystal. Closed circles shows the one obtained by the improved crystal .

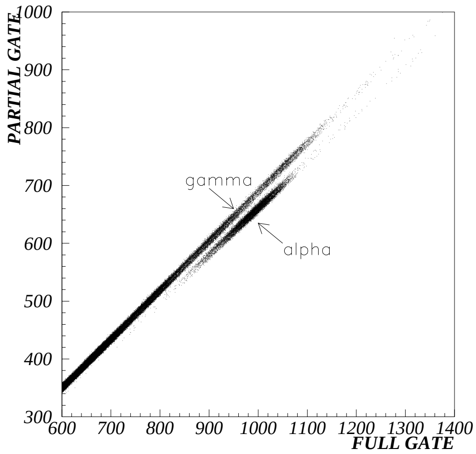

Figure 2: The two dimensional charge distribution spectrum which was obtained by PSD.

the one which was integrated fully. The two loci were very clearly separated.There are many works for PSD. However, all the works applied a complicated analysis[8][9] and needed many expensive circuits. We have shown that the precise PSD was performed by the simplest way and obtained the excellent result.

The peak yield of the α rays corresponds to the radioactivity as 11.27$\pm$0.10mBq/kg. This radioactivity was about one thousand times as large as the radioactivity of U-chain which was determined by the delayed coincidence method. The origin of this peak due to α rays was probably airborne radon, thus we concluded that the main compornent of this peak is due to α rays of ^{210}Po.

Our goal is the concentration of both U-chain and Th-chain less than 1μBq/kg. It is important to investigate not only ^{214}Po but also progeny of ^{220}Rn so as to develop a best method for a creation of an extremely high purity NaI(Tl). In the future, the high purity and large volume scintillator crystal segment will be developed to study dark matter and neutrino properties.

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