Study for Improvement of NaI(Tl) Scintillator for WIMPs Search

S. Yoshida[a], T.Itahashi[a], K.Fushimi[c], T.Kishimoto[b], N.Kudomi[a], K.Matsuoka[b], Y.Nagai[a], K.Takahisa[a], S.Umehara[b], H.Ejiri[a,d], N.Itatani[e], M.Hori[e], and Y.Yanagida[e]

[a]*Research Center for Nuclear Physics (RCNP), Ibaraki, Osaka 567-0047, Japan*
[b]*Department of Physics, Osaka Univ., Toyonaka, Osaka 560-0043, Japan*
[c]*Faculty of Integrated Arts and Science, Univ. of Tokushima, Tokushima 770-0814, Japan*
[d]*International Institute for Advanced Study (IIAS), Kizu, Kyoto , Japan*
[e]*Horiba Co. Ltd, Minami-ku, Kyoto 601-8510, Japan*

The sensitivity for spin independent interaction of NaI(Tl) detector with WIMPs is strongly dependent on the energy threshold[1]. The number of photoelectrons(P.E.) of the ELEGANT-V NaI(Tl) detector(ELE-V/NaI) is around 2.0 photoelectrons/keV at both ends of the detector, which is inferior to DAMA/NaI detectors($\sim$5.5 photoelectrons/keV[2]) because of the detector length and of the surface condition of the NaI(Tl) detector. Consequently, the energy threshold of ELE-V/NaI could not be set as low as near 2keV, which is achieved by the DAMA/NaI experiment. Hence the possible improvements have been considered for the energy threshold of the present NaI(Tl) detector.

In addition, the background event rate at low energy region is about 5 times higher than that of DAMA/NaI, and it affects the sensitivity of both spin independent and dependent interactions of the NaI(Tl) detector with WIMPs. From the background evaluations more than 50% of the observed event rate with the simple setup of NaI(Tl) detectors comes from the internal radioactivities such as ^{210}Pb[1]. In order to reduce the background rate, a pure crystal with much less activities, especially for ^{210}Pb, has to be prepared. However, the development to prepare such crystal is not easy. Actually, the internal radioactivities in the recently developed NaI(Tl) detector[3] were about as twice as those in ELE-V/NaI detectors, and the measured activities for each four detectors were not uniform. So that, it is not always possible to make more radioactive free detector than the present one in spite of the usage of the recent technologies.

Another background origins might be due to materials used for the detector. In spite of careful examinations, the background rates from materials used for the detector system were not negligible. Though the materials used for NaI(Tl) detector were also checked, they must be re-examined and if they contain appreciable amount of activities, they must be replaced with less contaminated materials.

From these considerations, the following studies are made to improve the sensitivity by using the present NaI(Tl) crystal. The module selected for this study is the cracked one[1].

1. **Improvement of the energy threshold**
   - In order to increase the number of photoelectrons at the PMTs, the length of the NaI(Tl) detector is shortened to be a half(480mm) of the present one.
   - The surface of the NaI(Tl) crystal is polished to have higher reflection efficiency at the surface.
   - The reflector materials are carefully re-selected to maximize the reflection efficiency of scintillation photons.

2. **Reduction of background**
   - In order to reduce the background due to the materials used for the detector, materials with less radioactivities were pre-selected by the low background Ge detector[4].

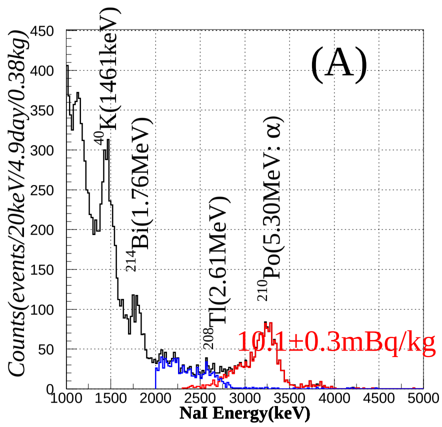
- The surface of the NaI(Tl) crystal is shaved off to eliminate the ^{210}Pb contamination

By means of these major and minor modifications, the energy threshold and the background rate might be improved.

As for the selection of reflector, the measurement of relative reflection efficiency of scintillation photons in NaI(Tl) scintillator was carried out. In order to simulate the geometry of the renewal detector, the used detector has the dimension with 30mm$\phi\times$ 150mm, which is similar to the ratio of renewal detector(102mm $\times$ 480mm). From the measured reflection efficiencies for scintillation photon, the combination of the 3 layers of expanded PTFE reflector and a layer of Aluminized mylar is selected as the materials for reflector[4].

In order to avoid the re-attachment of ^{222}Rn, it is important to know the processing conditions for shaving off the surface and housing(encapsulating) the detector, and also to check the radon concentration in the nitrogen gas used for the ventilation of the dry box used for the process. The measurement was carried out at Horiba. Co. Ltd. with the high sensitive radon detector[5]. The radon concentration in nitrogen gases into and out from the dry box are 11.0$\pm$7.8 and 25.9$\pm$13.0mBq/m^3, respectively. From the measurement, the additional amounts of ^{210}Pb in the shaving off process is estimated to be less than 0.05mBq/kg, which is two orders of magnitude less than the amount in NaI(Tl) before processing. Hence it is expected to be certainly worthwhile to shaving off the surface.

In order to investigate the effect of shaving off the surface of the NaI(Tl) detector, the preliminary test was carried out with the test detector. The test detector was made by cutting the crystal from ELE-V/NaI(Tl), which will be used for renewal detector and has the dimensions of 2 inch$\phi\times$ 2 inch. The observed energy spectrum is shown in Fig.1(A), and the amounts of ^{210}Po was 10.1$\pm$0.3mBq/kg. Consequently, it turned out that the internal ^{210}Pb contamination can not be reduced by shaving off the surface of NaI(Tl), contrary to the expectation. Hence, the ^{210}Pb is not located on the surface but in the whole volume of the NaI(Tl) crystal(bulk).



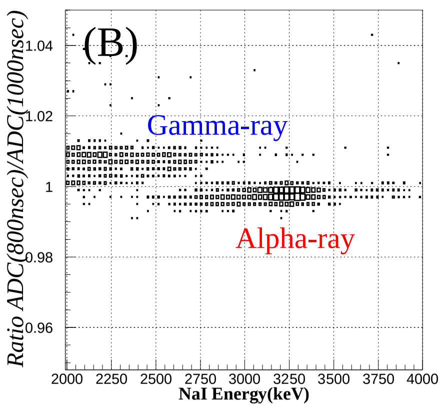


Figure 1: (A)Observed energy spectrum with the NaI(Tl) detector brought by cutting ELE-V/NaI sample. α events and e/γ events are discriminated above 2MeV. (B)The illustration of PSD technique for the discrimination between α and e/γ events.

References

[1] S. Yoshida, Doctral Thesis(2002), Osaka University.
[2] R. Bernabei *et al*, II Nuovo Cimento A112 (1999) 545.
[3] S. Umehara *et al*, to be appeared in the publication of Nucl. Instr. and Method Sec.A
[4] RCNP Annual Report(2001)
[5] E. Choi *et al*, Nucl. Instr. and Meth. A459 (2001) 177