MOON for Double-Beta Decays and Neutrino Nuclear Responses

K.Fushimi¹, Y.Kameda¹, K.Harada¹, S.Nakayama¹, H.Ejiri², T.Shima², K.Yasuda³, R.Hazama⁴ and K.Imagawa⁵

1. Institute for Socio Arts and Sciences, The University of Tokushima, Tokushima 770-8502, Japan
2. Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan
3. Department of Physics, Osaka University, Toyonaka, Osaka 560-0047, Japan
4. Department of Engineering, Hiroshima University, Higashi Hiroshima, Hiroshima 739-8527, Japan
5. Horiba Ltd. Kyoto city, Kyoto 601-8510, Japan
E-mail: kfushimi@ias.tokushima-u.ac.jp

Abstract. Thin and wide area inorganic crystal was tested for double beta decay experiment. The thin NaI(Tl) whose dimension of 18cm × 18cm × 0.5cm was developed. The energy resolution at Q−value of ¹⁰⁰Mo was obtained less than 3% in full-width-half-maximum. Although the backscattering of electrons suffers the detection efficiency, the NaI(Tl) has the advantage for double beta decay experiment.

1. MOON detector for double beta decay

Neutrino-less double beta decays (0νββ) are quite realistic and sensitive probes for the Majorana nature of the neutrino. 0νββ experiments provides the absolute mass and the CP phase which are the important parameters in the unified theories beyond the standard model. Recent experimental and theoretical studies are given in review articles and references [1, 2, 3].

The interesting range of the effective neutrino mass is between 30meV (quasi-degenerate:QD) and 100meV (inverted-hierarchy:IH). The live time of 0.1 ~ 1ton·yr and the favorable nuclei such as ⁸²Se, ¹⁰⁰Mo and ¹⁵⁰Nd are needed to search for the 0νββ events. Moreover, the good energy resolution is the key factor for the 0νββ decay experiments, since it is necessary to reject the most serious background due to the double beta decays with two-neutrino emission (2νββ).

The MOON (Mo/Majorana Observatory Of Neutrinos) detector is a multi-layer detector modules for double beta decay experiment [4, 5]. We aimed to develop the detector with the energy resolution about 3% in FWHM at the Q-value (~3MeV). We employed NaI(Tl) detectors whose energy resolutions are quite good. Since the backscattering effect of NaI(Tl) on low-energy electrons is not small, we have to use a higher threshold level for detector signals, and the total efficiency for 0νββ may be reduced. We studied the efficiency for 0νββ with Monte Carlo simulations, and the loss of the efficiency was found to be about 30%, which is still acceptable for our purpose.
2. Performance of thin and large area NaI(Tl) scintillator

The dimension of the thin and wide area NaI(Tl) crystal is 18cm×18cm×0.5cm. The crystal was encapsulated with thin aluminum sheet and quartz light guides to avoid the humidity. Scintillation photons are guided to the edge of the NaI(Tl) crystal by total reflection and a reflector with high reflective efficiency. Two thin NaI(Tl) modules were piled up, the enriched $^{100}$Mo sheet was inserted between two NaI(Tl) modules. The enrichment of $^{100}$Mo was 85%. The thickness of the source was 40mg/cm$^2$ and the total effective mass of $^{100}$Mo was 11.02g.

Two types of photomultiplier tubes (PMTs) were contacted at the edge of quartz light guides by optical grease. Two modules of 3 inches diameter PMTs were contacted on each edges in order to collect scintillation photon. One module of 0.75 inches square PMT were contacted on each edges in order to distinguish the layer in which the event occurred.

2.1. Energy resolution

The energy resolution was measured by irradiating several mono-energy gamma-rays from standard gamma-ray sources. The energy dependence of the energy resolution was shown in Fig.1. The energy resolution depends on inverse square of the energy. The energy resolution at the $Q$-value of $^{100}$Mo (3.034MeV) was extrapolated from the fit. About 3% of FWHM was obtained, which is good enough for $0\nu\beta\beta$ experiment.

![Figure 1. The energy dependence of the energy resolution in full-width-half-maximum (FWHM).](image)

2.2. Low background test

The test experiment was performed at the second laboratory in OTO Cosmo Observatory. OTO Cosmo Observatory is located 100km south from Osaka and 150km east from Tokushima. It is easily accessible site and enough depth (800mwe) for small scale experiment [6]. The thin NaI(Tl) detector system was installed into a shield which was used for ELEGANT-V [6]. Seven modules of large volume NaI(Tl) scintillator whose dimension was 10.1×10.1×101cm$^3$ were placed below and above the thin NaI(Tl) detectors. The whole detector was covered with an air-tight container and 10cm thick pure copper shield and 15cm thick pure lead shield. Pure nitrogen gas was flushed into the air-tight container to remove radioactive Rn gas. The radioactivity in the air-tight container was kept as low as 150mBq/m$^3$.

Test measurement for double beta decay was performed for half month with and without Mo-source film. Data analyses to distinguish two layer was successfully performed. Tagging of the layer was performed by using small PMTs. Due to large contamination of $^{40}$K and U-chain in aluminum flame of the detector, the background was not sufficiently reduced in the energy...
region of interest. However, the detector system worked well with good selectivity and the energy resolution.

3. Future prospect
The thin and wide area NaI(Tl) crystal was developed for studying nuclear rare processes. The energy resolution was enough good for not only neutrino-less double beta decay but also for dark matter search. A plastic scintillator is extensively applied to double beta decay experiments [4, 5, 7, 8] because of small backscattering ratio and low cost. However, it has been difficult to develop the plastic scintillator with the energy resolution below 4% in FWHM. The NaI(Tl) scintillator was shown that it is suitable for double beta decay experiment because of the good energy resolution. Figure 2 shows the dependence between the sensitivity for neutrino-less double beta decay and the live time. The sensitivity to the effective neutrino mass reaches to 20\(\text{meV}\), it is important to explore the inverted hierarchy of neutrino. One need to carry out the experiment with more than 10 ton-year of live time. In the case of long live time, the NaI(Tl) has better sensitivity for neutrino mass.

![Figure 2](image)

**Figure 2.** The sensitivity for effective neutrino mass as a function of the experimental live time.
Open circle: The case for NaI(Tl). Triangle: The case for plastic scintillator (PL).

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References
[1] H.Ejiri, Jour. of the Phys. Soc. Japan 74 2101.
[2] F.T.Avignone, S.Elliott and J.Engel, Rev. Mod. Phys. 80 (2008) 481.
[3] J.Vergados, Phys. Rep. 361 (2002) 1.
[4] H.Ejiri, Mod. Phys. Lett. A22 (2006) 1277.
[5] H.Ejiri et al., Euro Phys. J. 162 (2008) 239.
[6] H.Ejiri et al., Nucl. Instr. & Meth. in Phys. Res. A302 (1991) 304.
[7] R.Arnold et al., Phys. Rev. Lett. 95 (2005) 182302.
[8] F.Mauger et al., In this proceedings.