PROCEEDINGS OF SCIENCE

R&D of water-based liquid scintillator as a reactor anti-neutrino detector

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Nonflammable and nonvolatile liquid scintillator is preferable for a nuclear reactor monitor which is one of the safeguards of IAEA (International Atomic Energy Agency). We have been developing a wagter-based scintillator for this use. We were able to dissolve a luminescent agent (PPO) in water with a surfactant. The scintillators were contained in a small glass vial (4cm diameter and 8cm height). We irradiated the vial with gamma-rays from a cobalt 60 source and measured the light yield of Compton scattered electrons. The maximum energy of Compton scattered electron is 1.12 MeV and its light yield was estimated to be 9.99 ± 0.17 photoelectrons in the scintillaor comprised of 70 % water, 30 % SDS and 30 g/l (H_2O) PPO. It is about 1/26 light yield of the conventional organic solvent scintillator comprised of pseudocumene and 3 g/l PPO. We also measured its aging. The light yield changed from 11.6 to 9.18 photoelectrons over the period of one year. We could dissolve gadolinium in that scintillator as gadolinium sulfate. The obtaied light yield was 9.55 ± 0.38 photoelectrons. We tried to use commercially avalable liquid detergent as a surfactant. PPO dissolved and the light yield was 6.43 ± 0.07 photoelectorns for the 50 % water, 50 % detergent, and 30 g/l (H_2O) PPO.

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1. Introduction

Neutrino energy measurement is very important not only for a neutrino oscillation experiment but also for a nuclear reactor monitor requested by IAEA (International Atsomic Energy Agency) as one of their safe guards against misuse of nuclear technology and nuclear materials. The requirements for a reactor monitor are that it be nonflammable and nonvoatile since it is used near a reactor. Organic solvent liquid scintillators which have been used so far in the reactor neutrino experiment are not suitable for the nuclear monitor since they are both flammable and voaltile and furthermore are harmful to the human body. Therefore water-based scintillator is suitable for a nuclear reactor monitor. Gadolinium is usually loaded in the scintillator to identify neutrino interactions (inverse beta decays). They are identified by a well-known delayed coincidence of a prompt positron signature followd by a delayed neutron captured by gadolinium. Since gadolinium dissolves in water as gadolinium salfate, water-based scintillator is also suitable for a nuclear reactor monitor in this point. One of the problems of water-based scintillator so far has been its low light yield. A surfactant is added since commonly used luminescent agents do not dissolve in water. This time we used PPO as a luminescent agent and sodium dodecyl sulfate (SDS) as a surfactant. We also tried to use commercially avalable liquid detergent as a surfactant.

2. Light yield measurement and calibration

We measured light yield of Compton scattered electrons by gamma rays form a cobalt 60 source and estimated the number of photoelectrons for the electrons with maximum energy. The maximum energy of Compton scattered electrons is given by

$$E_e^{max} = E_\gamma - \frac{E_\gamma}{1+\frac{2E_\gamma}{m_e c^2}}, \tag{2.1}$$

where E_γ is the energy of induced γ ray and $m_e c^2$ is the electron mass. Since a cobalt 60 source emits 1.17 MeV and 1.33 MeV gamma rays, the maximum energy of Compton scattered electrons is 1.12 MeV in this case.

The original energy distribution of Compton scattered electrons is shown in Fig.1(left). Due to the finite energy resolution, the practical distributions are smeared as shown in center and right plots of Fig.1(center and right). The center one is a simulation result with energy resolution $10\%/\sqrt{E}$ and the right one is a measurement result. However the two energy peaks are merged into one and we can see no edge in the distribution, we can define the maximum energy (Compton edge) as the value at the half maximum of the peak as described below. Fig.2 shows the simulated energy distributions of Compton scattered electrons with various energy resolutions [1]. Althogh the position of the peak changes as a function of the energy resolution, the value at the half maximum is almost constant. The definition of Compton edge is reasonable.

Fig.3 shows the setup for the light yield measurement. The liquid scintillator was contained in a small glass vial (ϕ 4 cm and 8 cm height). We irradiated the vial from the side with gamma-rays from a cobalt 60 source. The scintillation light was measured at the bottom by PMT.

We calibrated the light yield with a blue LED, and the ADC values were converted to the number of photoelectrons. If we assume the light yield follows a Poisson distribution, the number

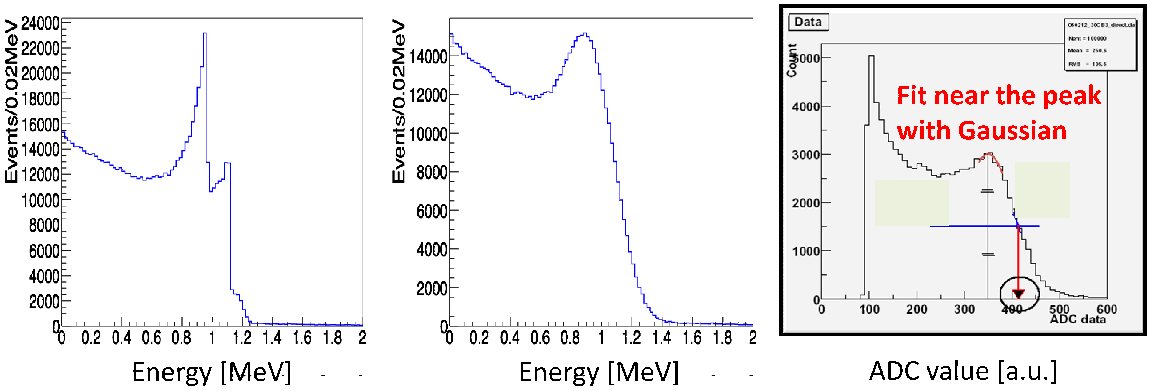

Figure 1: Compton electron energy distributions.

of photoelectrons (pe) are given by

$$pe = \left(\frac{\mu}{\sigma}\right)^2, \tag{2.2}$$

where μ and σ are the mean and standard deviation of the ADC distribuion, respectively. Varying the brightness of LED, we can get the relation between the number of photoelectrons and the ADC value as shown in Fig.4. The inclination of the line is the calibration factor. We can obtain the number of photoelectrons as the ADC value multiplied by the calibratiojn factor.

3. Results

We dissolved PPO in water with sodium dodecyl sulfate (SDS) as a surfactant. We observed a clear peak in the light yield distribution (Fig.5) and increase of light yield with PPO concentration until 30 g/l(H_2O). Fig.6 shows the light yield distributions for the five samples of scintillator comprised of 70 % water, 30 % SDS, and 30 g/l (H_2O) PPO. The light yield for the Compton edge was 9.99 ± 0.17 [pe]. The error is the RMS of these five samples. This light yield corresponds to about 1/26 of that of conventional organic solvent scintillators, which was 260 pe by our measurement.

We monitored aging for this scintillator. The vials were stored at room temperature (about 20 $^\circ$C) in a dark place. We observed crystals at the bottom of the vial after one year (upper-left of Fig.7). Although there was no significant light yield measured for the supernatant (upper-right of Fig.7), the crystal easily dissolved by shaking the vial (lower-left of Fig.7) and the light yield was 9.18 photoelectrons (lower-right of Fig.7), which had been 11.6 photoelectrons one year before. The light yield deterioration for one year was little.

We dissolved gadolinium in this scintillator as gadolinium sulfate ($Gd_2(SO_4)_3$). The number of photoelectrons for the Compton edge was 9.55 ± 0.38 [pe] for the scintillator of which gadolinium concentration was 0.2 wt %. There was no significant difference from the no gadolinium-loaded one.

We tried to use a commercially avalable liquid detergent as a surfactant. We could dissolve PPO and obseve significant light yield. The distributions are shown in Fig.8 and the mean light yield of five samples was 6.43 ± 0.07 [pe]. In this case, gadolinium did not dissolve in it.

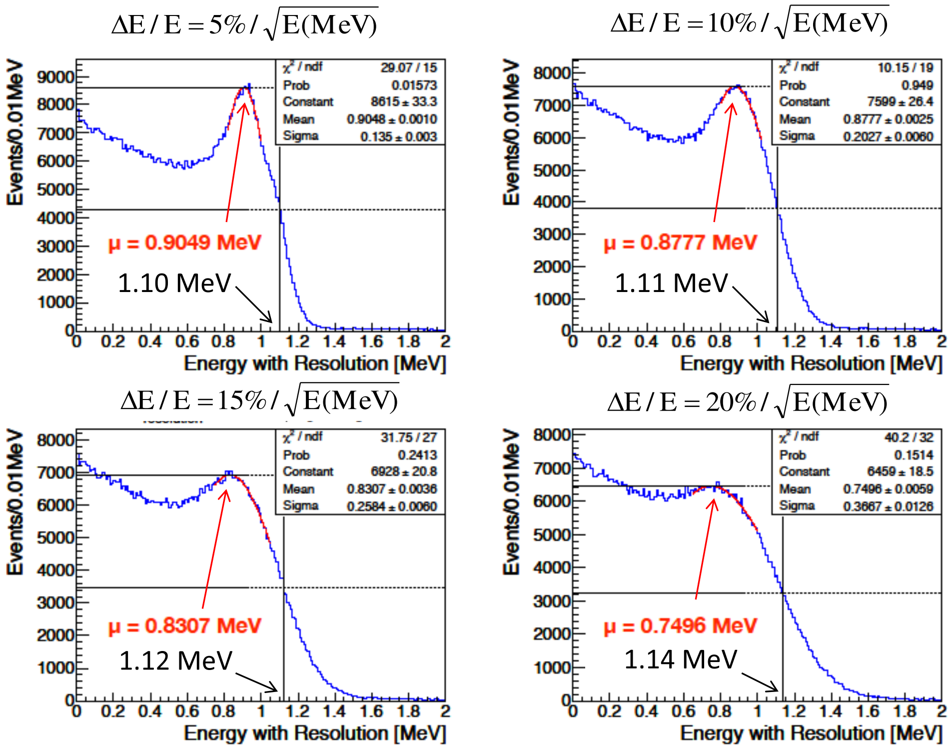

Figure 2: Simulated energy distributions of Compton scattered electrons with various energy resolutions. Althogh the peak position changes as a function of energy resolution, the value at the half maximum of the peak is almost constant.

4. Summary

We have been developing water-based scintillator for the use as a nuclear reactor monitor. We could obtain the significant light yield of about 10 photoelectrons for the scintillator comprised of 70 % water (solvent), 30 % SDS (surfactant), and 30 g/l(H_2) PPO (luminescent agent) in the 4cm diameter and 8cm height vial. This light yield corresponds to about 1/26 of that for the conventional organic solvent scintillator. No significant light yield deterioration was seen after one year. Gadlinium was dissolved in the scintillator as gadolinium sulfate ($Gd_2(SO_4)$ and we obtained about the same light yield as that for no gadlinium-loaded one. Instead of SDS, we tried to use commercially avalable detergent as a surfactant. Obtained light yield was about 6.5 photoelectrons for the scintillator comprised of 50 % water, 50 % detergent, and 30 g/l (H_2O) PPO.

5. Acknowledgements

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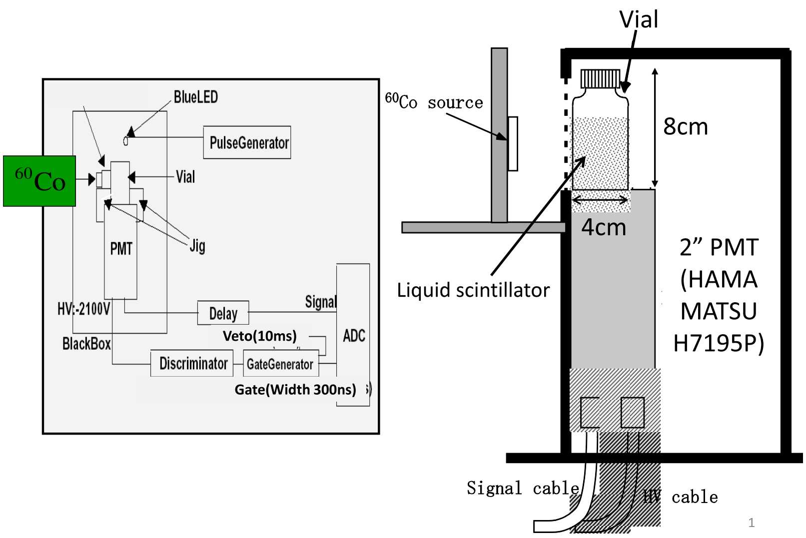

Figure 3: Setup for the light yield measurement.

References

[1] Simulated by H. Furuta (Tohoku University) and K. Nakajima (Osaka University)

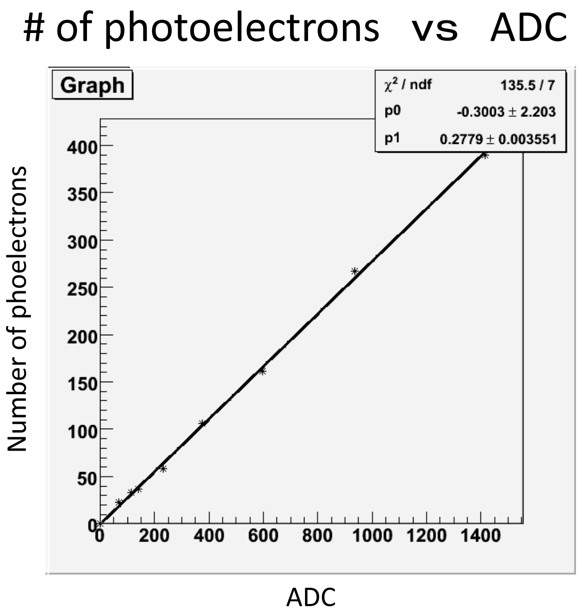

Figure 4: Number of photoelectrons as a function of ADC value.

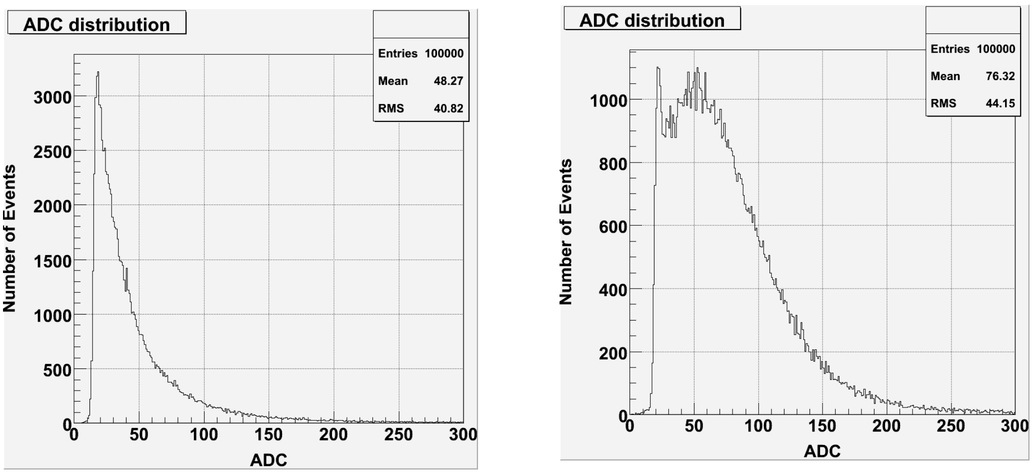

Figure 5: Light yield distributions without (left) and with (right) PPO. We can see clear Compton peak in the right distribution.

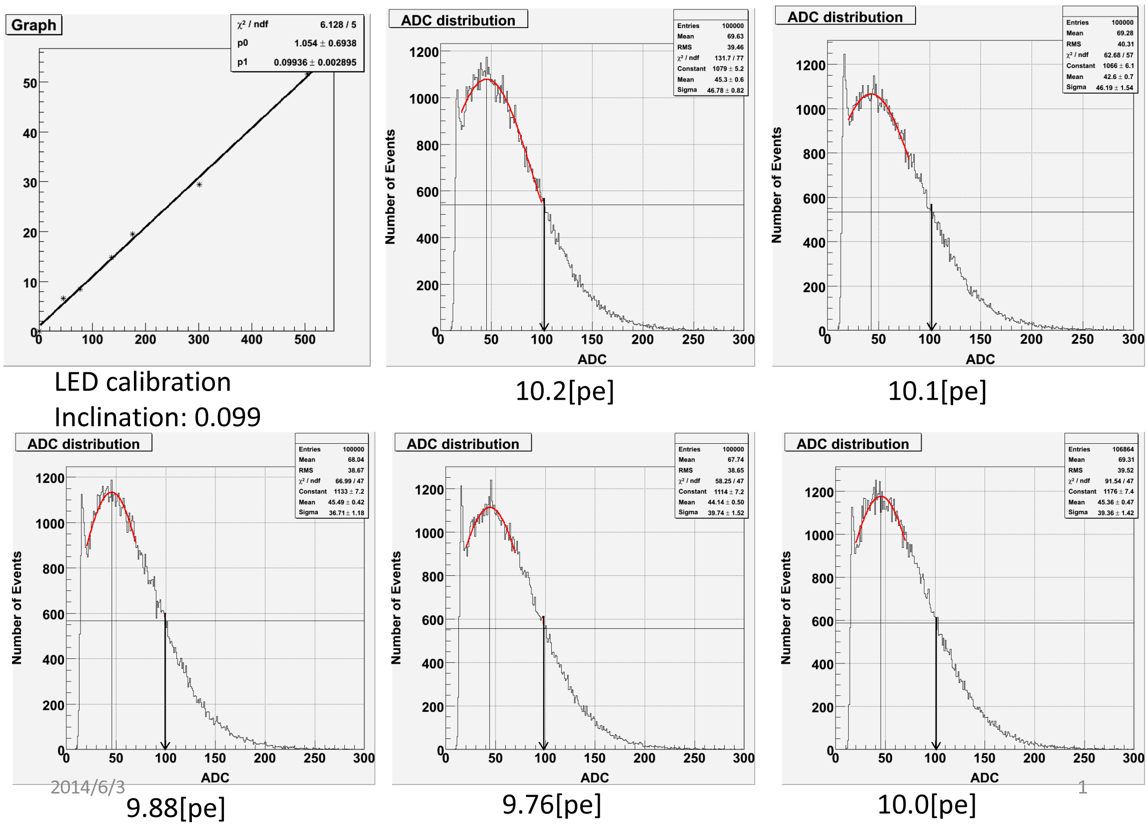

Figure 6: Light yield distributions for the scintillator comprised of 70 % water, 30 % SDS and 30 g/*l* (H_2O) PPO. Upper-left shows the result of light yield calibration.

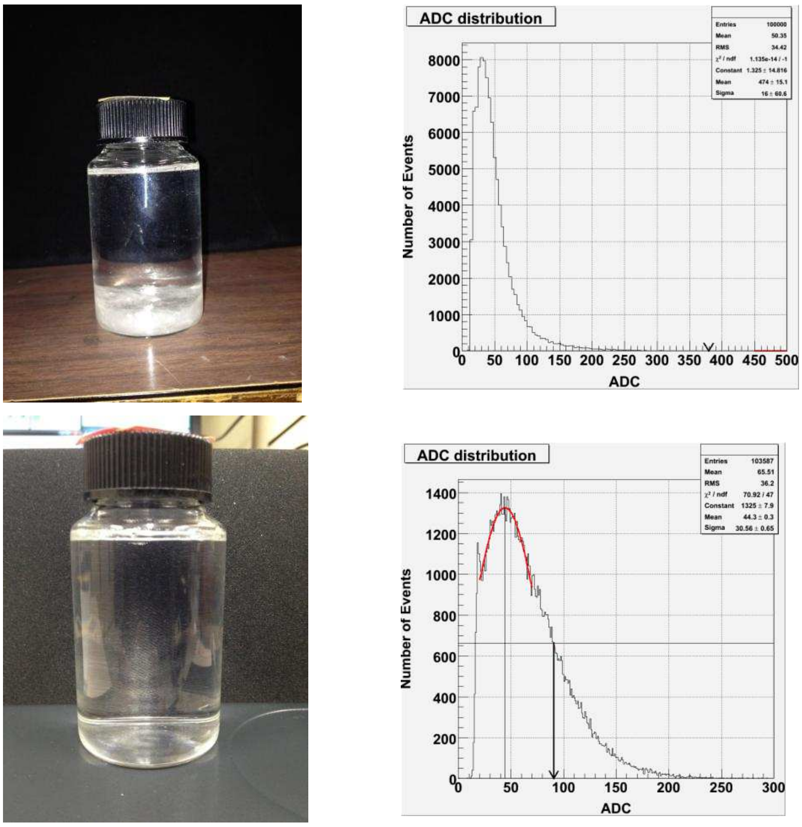

Figure 7: Aging of the scintillator (70 % water, 30 % SDS, ans 30 g/*l* (H_2O) PPO). Some crystals appeared after one year (upper-left) and no significant light yield was measured for the supernatant (upper-right). By shaking the vial, it easily dissolved (lower-right) and the light yield was 9.18 photoelectrons (lower-right).

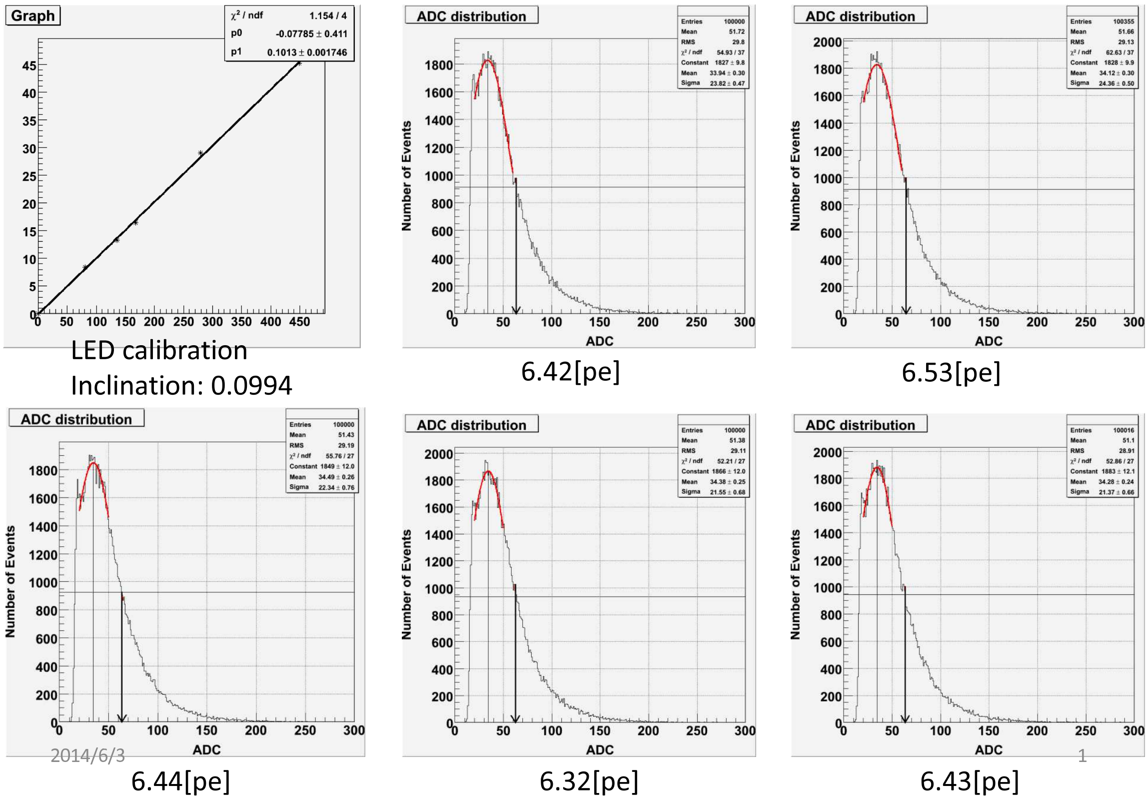

Figure 8: Light yield distributions for the scintillator comprised of 50 % water, 50 % detergent, and 30 g/*l* (H_2O) PPO. Upper-left shows the result of light yield calibration.