ICANS-XI International Collaboration on Advanced Neutron Sources
KEK, Tsukuba, October 22-26, 1990

Scintillation Detector System in Neutron-Nucleus Experiments

H.M.Shimizu* , T.Adachi** and Y.Masuda**

* Department of Physics, Kyoto University
Kyoto 606, Japan
** National Laboratory for High Energy Physics
1-1 Oho Tsukuba 305, Japan

I. Introduction

Very large enhancement of parity-nonconservation (PNC) effect in the neutron-nucleus reaction has been studied for a decade.[1,2,3,4] The enhancement of the PNC effect is interesting phenomena itself. And furthermore, it has another interesting point, namely, the mechanism of enhancement is expected also for time reversal symmetry breaking terms[5,6,7,8]. We have been studying longitudinal asymmetries in (n,γ) reaction cross sections denoted by $A_{L,\gamma}$ for several nuclei[3]. Very large enhancement up to 10^6 of magnitude has been observed in the radiative capture p-wave resonance of ^{139}La at the incident neutron energy of 0.734 eV. In the experiment, capture γ rays and transmitted neutrons were counted as a function of the neutron energy by using the time-of-flight (TOF) method. The γ-ray detection takes an advantage to identify the radiative capture reaction, while the neutron transmission includes large contribution of the neutron scattering. In this report, we will describe our current experimental arrangement and recent results.

II. Experimental Arrangement

The experiment was carried out in a polarized neutron beamline at KENS. The schematic view of our experimental arrangement is shown in Fig. 1. Neutrons were transversely polarized upon transmission through a dynamically polarized proton filter which was placed at 5.2 m from the neutron source. A typical neutron polarization around E_n = 1 eV was about 70%. A typical instantaneous incident neutron intensity was 3×10^7 polarized neutrons/sec/cm^2/eV (E_n=1 eV) at 6.6 m from the neutron source. A target was placed at 6.6 m from the neutron source. The neutron spin was rotated from the transverse to longitudinal direction following an adiabatic passage. The neutron helicity was reversed every 2.5 seconds.

A plastic scintillator for a beam monitor was placed at 4.5 m from the neutron source. Three sets of BaF_2 crystals were placed cylindrically surrounding the target for capture γ-ray detection at three polar angles with respect to the incident neutron momentum. The capture γ rays were detected inclusively with energy threshold of 1 MeV. Transmitted neutrons were detected by a ^{10}B loaded liquid scintillation counter located at 9.4 m from the neutron source.

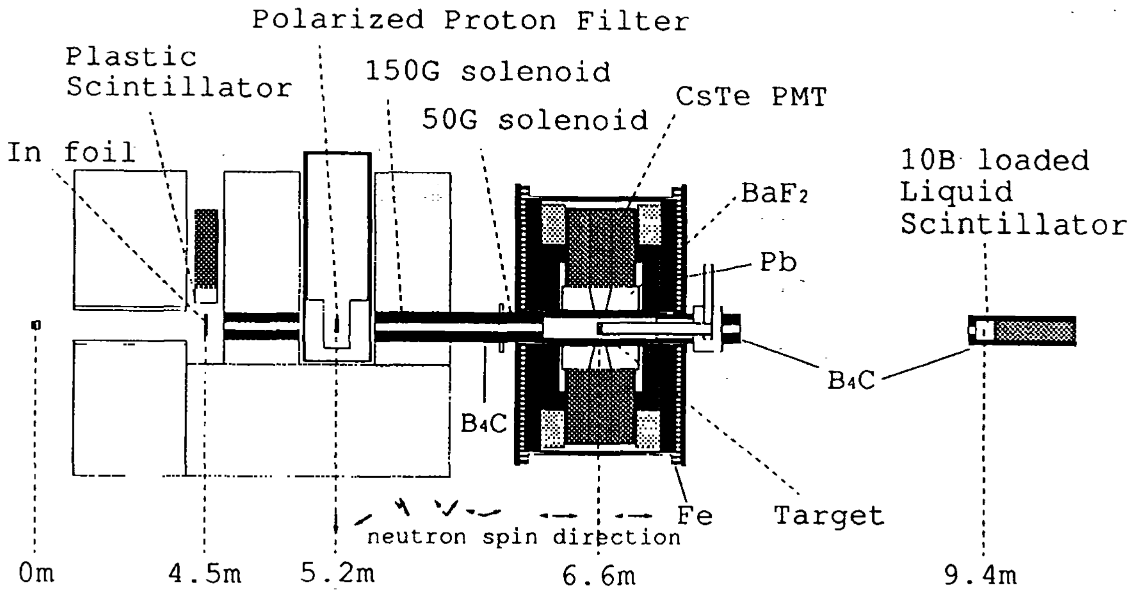


Figure 1.
Schematic view of our experimental arrangement

III. Counters

(a) Plastic Scintillator for Beam Monitor

An annular 0.02-mm thick indium foil was placed most upstream of our system for monitoring the number of incident neutrons by detecting capture γ rays from indium nuclei. A plastic scintillation counter was used for the detection of the capture γ rays, since it has a good timing characteristics. The scintillator size was 5 cm in thickness and 5 cm in diameter. A photomultiplier (Hamamatsu H1161) with bialkali photocathode and borosilicate window was used to detect the scintillation light from the plastic scintillator. The pulse width was about 10 ns in FWHM. Since plastic scintillator contains only low Z atoms, the contribution of the compton scattering is much larger than that of full energy absorption. The full energy absorption, however, is not necessary for the beam monitoring.

(b) ^{10}B Loaded Liquid Scintillator[9] for Transmission Measurement

An NE311A ^{10}B loaded liquid scintillator was used for the transmission measurement. ^{10}B nuclei are contained 2.4×10^{21} cm^{-3} in the liquid scintillator. Neutrons are detected by the following reactions.

$n + {}^{10}B \rightarrow {}^{7}Li + {}^{4}He + 2.792MeV$

$n + {}^{10}B \rightarrow {}^{7}Li^{*} + {}^{4}He + 2.310MeV$

The cross section of these reactions is about 600 barns at $E_n = 1$ eV. The scintillator size was 3.5 cm in thickness and 3.5 cm in diameter. Therefore, the detection efficiency is 99.4% for 1-eV neutrons. The kinetic energy of charged particle is converted to scintillation photons in organic liquid. The photomultiplier (Hamamatsu H1161) was used for scintillation light detection. Since the deposit energy is determined by the Q-value of these reactions, pulse height spectrum of neutron signal has a definite peak. Typical raw pulses obtained with neutron beam are shown in Fig. 2. The pulse width was about 15 ns. The separation of neutron pulse was remarkably good. Neutron pulses was extracted by using window type discrimination.

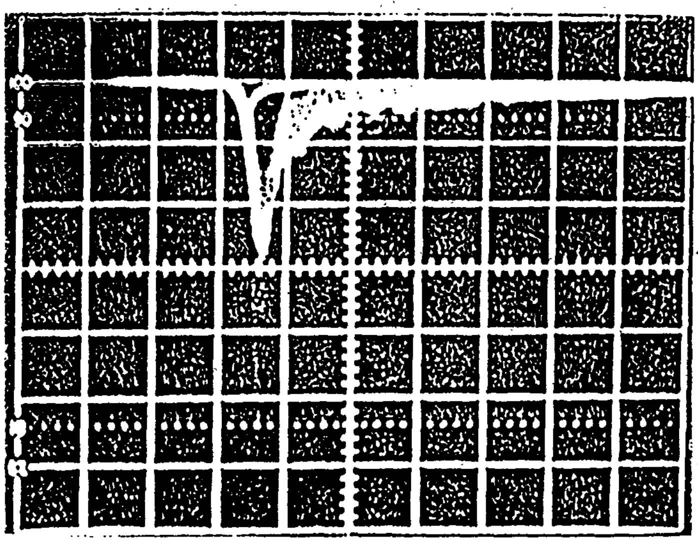


Fig. 2. Typical neutron signal of ^{10}B loaded liquid scintillator. The neutron signals form a clear band corresponding to reaction Q-value. The scale of x-axis is 20ns/div, y-axis 50mV/div.

(c) BaF_2 Crystal for Capture γ-Ray Measurement from the Target

BaF_2 crystals were used for the detection of capture γ rays from target nuclei. A solid angle of ϑ=30-150° and ϕ=0-360° was covered by the whole BaF_2 γ-ray counter. The thickness in the γ-ray emission direction was more than 6 cm. Since the radiation length of BaF_2 crystal (2.1 cm) is shorter than that of NaI(Tl) crystal (2.6 cm) which is commonly used for γ-ray detection, the full energy absorption efficiency of BaF_2 is better than that of NaI for the same dimension. BaF_2 crystal has two light emission peaks at 220 and 310 nm in wave length. The decay constants for the two components are 0.6 and 620 ns, respectively. Hamamatsu R329QTE photomultiplier with a CsTe photocathode was used to detect only the fast component of scintillation light which has a good timing characteristics. A quartz plate is used as a window for R329QTE so as to transmit the fast component light in the ultra violet region. Typical raw pulses of the fast component of BaF_2 scintillation light are shown in Fig. 3. The pulse width was about 10 ns in FWHM.

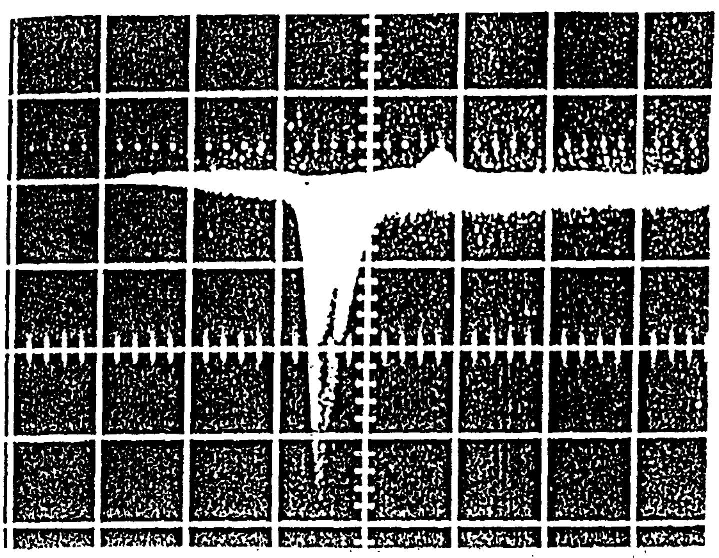


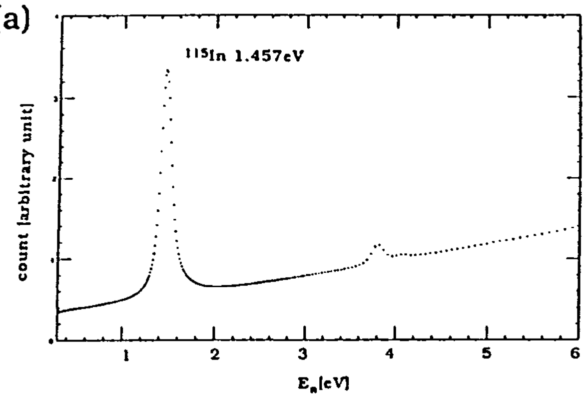
Fig. 3. Typical fast component signal of BaF_2 scintillator. UV (ultra violet) sensitive photomultiplier with CsTe photocathode and quartz window is used. The scale of x-axis is 20ns/div, y-axis 100mV/div.

IV. Results of $A_{L,\gamma}$ Measurement

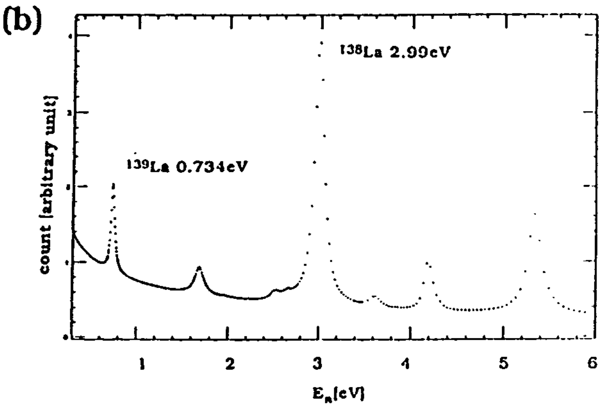
Typical TOF spectra obtained by the beam-monitor counter, BaF_2 γ-ray counter and transmission counter as a function of incident neutron energy are shown in Fig. 4. In the TOF spectrum of the beam-monitor counter, a resonance is found at E_n = 1.457 eV for ^{115}In. The count around the resonance peak was used to normalize the counts of the BaF_2 γ ray and the transmission counters. In the TOF spectra of the BaF_2 γ-ray counter and the transmission counter, a p-wave resonance of ^{139}La is found at E_n = 0.734 eV, and an s-wave resonance of ^{138}La at E_n = 2.99 eV. Small resonances were observed with a good signal to background ratio in the capture γ-ray measurement in comparison with the transmission measurement.

The preliminary results of $A_{L,\gamma}$ for several nuclei are listed in table 1. The longitudinal asymmetry corresponds to $\sigma_n \cdot \mathbf{k}_n$ correlation, which contains only the entrance channel quantities. The enhancement of the longitudinal asymmetry is explained by many theoretists.[7,10,11] The present results are consistent with the parity mixing in the entrance channel into the compound nucleus.

(a)



(b)



(c)

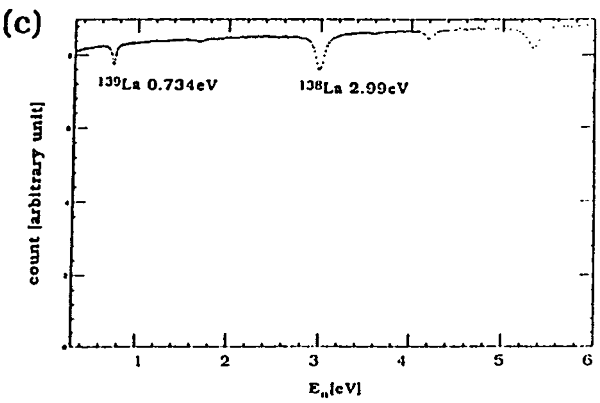


Fig. 4. Typical TOF spectra obtained by (a) beam-monitor counter, (b) BaF_2 γ-ray counter and (c) transmission counter. The x-axis is the incident neutron energy in eV, the y-axis is the counts in arbitrary unit. The (b) and (c) are the spectra for a 10-mm thick lanthanum target. Unlabelled small peaks are due to contaminations.

	^{139}La	^{81}Br	^{111}Cd
E_n[eV]	0.734	0.88	4.53
$A_{L,\gamma}$	(9.9±0.5)%	(2.4±0.5)%	-(1.0±0.5)%

Table 1. The preliminary results of $A_{L,\gamma}$ measurement using the present BaF_2 counter. The $A_{L,\gamma}$ for ^{139}La is consistent with our previous measurements.[3]

V. Development for Exclusive γ-ray Detection

In capture γ-ray measurement, many other PNC correlation terms can be observed. These correlation terms contain the quantities in the exit channel from the compound nucleus (k_γ or γ helicity). The similar enhancements are expected also for such correlations, for example, $\sigma_n \cdot \mathbf{k}_\gamma$ correlation term[12]. The inclusive detection of capture γ-rays is not sufficient to measure such correlation terms because of the following reason. Many γ-ray transitions are induced in deexcitation of the compound nucleus. The spectroscopic factor of each γ-ray transition is different in magnitude and sign. As the result, the PNC effect may be smeared after integrating the contributions of these γ-ray transitions. Therefore, the detection of specific transition is required.

Bismuth germanate (BGO) crystal is a hopeful candidate for this purpose. Better efficiency of full energy absorption can be obtained with smaller crystal size because of its short radiation length (1.1 cm). The compactness is an important point in actual measurement, since very large shields for background γ-rays and neutrons is required for a large detector. We studied the pulse height spectrum of 2"φx2" BGO by using several γ-ray sources. Hamamatsu H1161 photomultiplier was used for scintillation light detection. As the result, fill energy peak was observed clearly with energy resolution 8% in FWHM for 4.43-MeV γ rays as shown in Fig. 5. The decay constant of light emission of BGO is 300 ns, which is rather slow. But it is not problem because a typical counting rate of capture γ rays from the target is less than 100 kHz. We have built a BGO counter set (shown in Fig. 6) for the measurements of some correlations which contain exit channel quantities mentioned above.

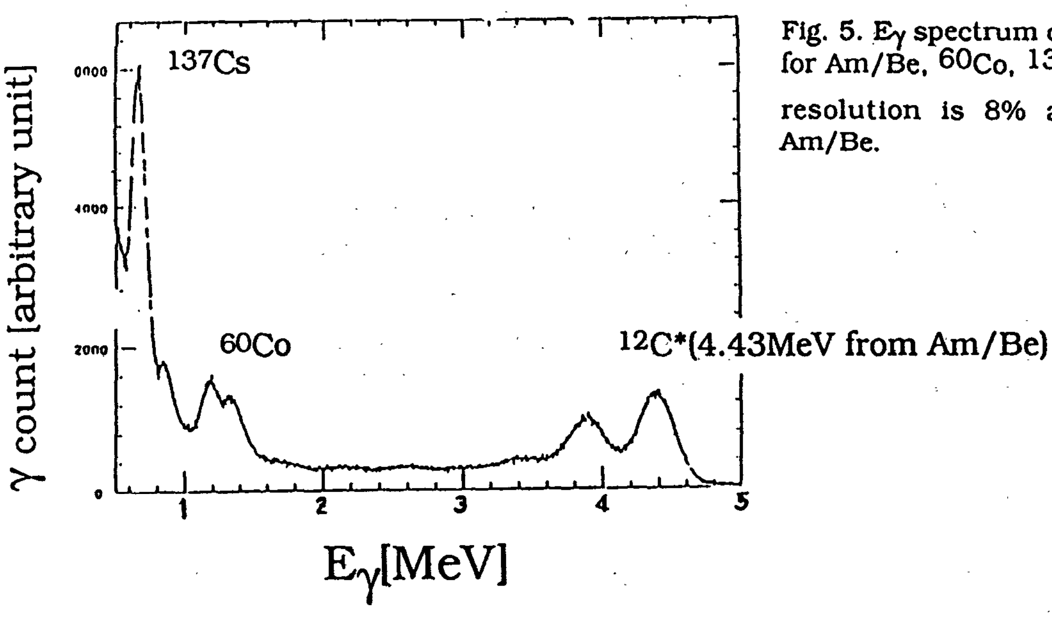


Fig. 5. E_γ spectrum of 2"φx2" BGO crystal for Am/Be, ^{60}Co, ^{137}Cs sources. Energy resolution is 8% at 4.43MeV γ from Am/Be.

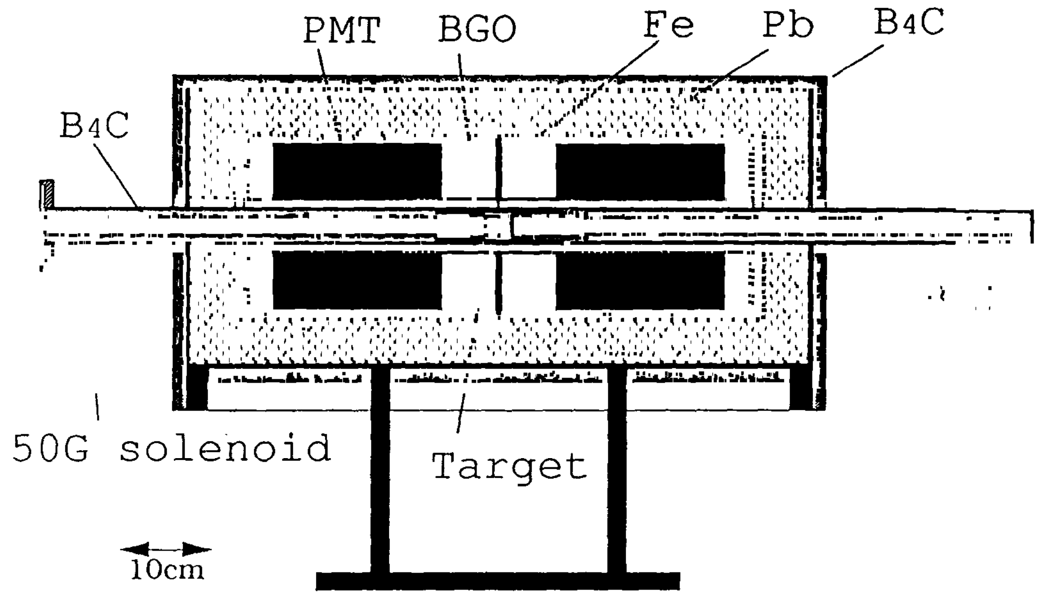


Fig. 6. Counter arrangement of BGO detector system.

The authors would like to thank Prof. A. Masaike, Prof. K. Morimoto for their helpful and valuable discussion. We also thank Prof. H. Sugawara, Prof. N. Watanabe and Prof. K. Nakai for their kind encouragements.

References

1. M.Forte, et.al., Phys.Rev.Lett. **45** (1980) 2088
2. V.P. Alfimenkov, Nucl.Phys. **A398** (1983) 93
3. Y. Masuda, et.al., Hyperfine Interactions **34** (1987) 143
   Y. Masuda, et.al., Nucl.Phys. **A478** (1988) 737c
   Y. Masuda, et.al., Nucl.Phys. **A504** (1989) 269
4. J.D. Bowman, et.al., Phys.Rev.Lett. **65** (1990) 1192
5. L.Stodolsky, Nucl.Phys. **B197** (1982) 213
   L. Stodolsky, Phys.Lett. **172B** (1986) 5
6. P.K.Kabir, Phys.Rev. **D25** (1982) 2013
   P.K. Kabir, Phys.Rev.Lett. **60** (1988) 686
7. V.E.Bunakov and V.P.Gudkov, Nucl.Phys. **A401** (1983) 93
8. Y.Yamaguchi, J. Phys. Soc. Jpn. **57**(1988)1525(L); ibid 2331
9. L.W.Bollinger and G.E.Thomas, Rev.Sci.Instr. **28** (1957) 489
10. O.P.Sushkov and V.V.Flambaum, Sov.Phys.Usp. **25** (1982) 1
11. Y.Yamaguchi, J. Phys. Soc.Jpn. **57**(1988)1518(L);ibid1522(L);ibid 3344.
12. V.V.Flambaum and O.P.Sushkov, Nucl.Phys. **A435** (1985) 352

Q(Y.Maeda): Would you tell me what kind of grease are used between the BaF_2 scintillator and the photomultiplier?

A(H.M.Shimizu): Air Contact!