Portable Neutron Detector Using Ce:LiCaAlF_6 Scintillator

Watanabe, Kenichi
Graduate School of Engineering, Nagoya University

Yanagida, Takayuki
Graduate School of Materials Science, Nara Institute of Science and Technology

Fukuda, Kentaro
Tokuyama Corporation

Koike, Akifumi
ANSeeN Inc.

他

出版情報：Sensors and Materials. 27 (3), pp.269-275, 2015-04-09. MYU K.K.
バージョン：

Sensors and Materials, Vol. 27, No. 3 (2015) 269–275
MYU Tokyo

S & M 1065

Portable Neutron Detector Using Ce:LiCaAlF_6 Scintillator

Kenichi Watanabe*, Takayuki Yanagida[1], Kentaro Fukuda[2], Akifumi Koike[3], Toru Aoki[4] and Akira Uritani

Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
[1]Graduate School of Materials Science, Nara Institute of Science and Technology, 8916-5 Takayama-cho, Ikoma, Nara 630-0192, Japan
[2]Tokuyama Corporation, 1-1 Mikage-cho, Shunan-shi, Yamaguchi 745-8648, Japan
[3]ANSeeN Inc., 3-5-1 Johoku, Naka-ku, Hamamatsu 432-8561, Japan
[4]Shizuoka University, 3-5-1 Johoku, Naka-ku, Hamamatsu 432-8011, Japan

(Received November 27, 2014; accepted February 4, 2015)

Key words: neutron detector, Ce:LiCaAlF_6 scintillator, portable detector

We fabricated a prototype portable neutron detector using a Ce:LiCaAlF_6 (Ce:LiCAF) scintillator and evaluated its basic performance. The weight of the fabricated detector including the battery is 800 g, significantly less than that of the conventional portable neutron detector, which weighs more than 5 kg. The neutron sensitivity of the fabricated detector is evaluated to be 2.3 cps/(μSv/h), comparable to that of the conventional detector. The gamma-ray intrinsic detection efficiency is evaluated to be less than 10^{-6}. The gamma-ray sensitivity is sufficiently low under ordinary circumstances. The expected count rate of the error counting due to the pile-up effect of gamma-ray-induced events is confirmed to be less than the background count rate for an incident gamma-ray rate of less than 10^4 gammas/s.

1. Introduction

Neutrons are widely used in various fields, such as security, nondestructive inspection, nuclear facilities, and so on. In addition, high-energy electron and ion accelerators, which are used as radiation generators in radiation therapy facilities, can be neutron sources. To manage the radiation safety of facilities, radiation detection and measurement play an important role. For detection of neutrons, the ^{3}He proportional counter has been used as the standard detector. However, ^{3}He gas is severely short in supply.(1,2) Therefore, development of alternative neutron detectors is required. Inorganic scintillators containing ^{6}Li or ^{10}B are promising due to their high neutron absorption cross sections. In particular, we focus on a Ce-doped LiCaAlF_6 (Ce:LiCAF) scintillator due to its excellent properties as a neutron scintillator. This scintillator has relatively high

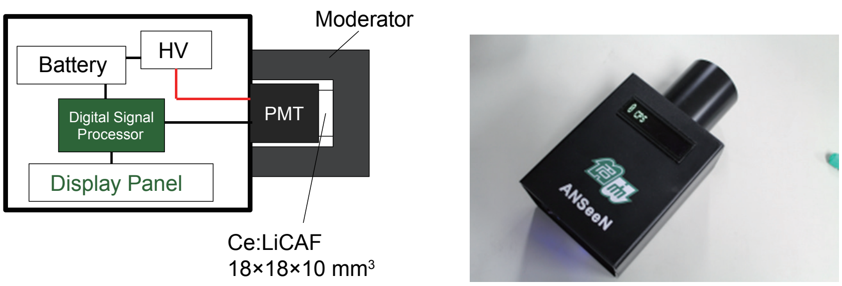
*Corresponding author: e-mail: k-watanabe@nucl.nagoya-u.ac.jp

light yield, high α/β, fast decay time, high transparency, and no hygroscopicity.[3] The Ce:LiCAF scintillator also has the ability of pulse shape discrimination between neutron and gamma-ray events.[4,5] Although scintillator-based neutron detectors suffer from gamma-ray interference, a neutron detector using Ce:LiCAF is insensitive to gamma rays due to the excellent properties mentioned.

Neutrons over a wide energy range from the thermal to MeV region occur in working areas of nuclear facilities. Although thermal neutron detectors using ^{3}He, ^{6}Li, and ^{10}B are highly sensitive to low-energy neutrons, the sensitivity of these detectors decreases with increasing neutron energy. In order to maintain relatively high sensitivity over a wide energy range, these detectors are often surrounded by a neutron moderator. High-energy neutrons are slowed down through collisions with light atoms in the moderator. The moderated neutrons can interact with a high absorption cross section with detector media such as ^{3}He, ^{6}Li, and ^{10}B. Neutron detectors which cover a wide energy range are often heavy due to the presence of the moderator. Conventional portable neutron detectors weigh more than 5 kg, which limits their portability. In order to increase the neutron sensitivity over a wide energy range, neutron detectors should be constructed using a material with a high macroscopic cross section, which is defined as the product of microscopic cross section and atomic density. Since transparent neutron scintillators, which are solid materials and have large atomic density, can have a larger macroscopic cross section than ^{3}He gas detectors and a relatively large sensitive volume, they are promising for fabricating highly sensitive neutron detectors over a wide energy range. In particular, the Ce:LiCAF scintillator is one of the most promising candidates as a detection medium for a sensitive portable neutron detector due to its high macroscopic cross section and low gamma-ray sensitivity. In this paper, we report the fabrication of a prototype portable neutron detector using Ce:LiCAF and evaluate its basic performance.

2. Portable Neutron Detector Using Ce:LiCAF

We fabricated a prototype portable neutron detector using a Ce:LiCAF scintillator (ANSeeN, ANS-NGS001MW). Figure 1 shows the block diagram and image of the fabricated detector. The size of the scintillator was 18 × 18 × 10 mm^{3}. The scintillator



(a) (b)

Fig. 1. (Color online) (a) Block diagram and (b) image of the fabricated portable neutron detector using Ce:LiCAF scintillator.

was directly mounted on a photomultiplier tube (PMT, Hamamatsu, R7600U-200) window. The scintillator was also placed in a cylindrical polyethylene moderator of 60 mm diameter and 70 mm length. A high-voltage power supply for the PMT and a battery were built on the chassis of the detector. An anode signal was fed into a microcomputer-based digital signal processor to analyze signal pulse height and pulse shape. Signals were digitized by an analog to digital converter (ADC) with a sampling rate of 400 k samplings per second. The signal pulse height reflects the deposition energy of neutron or gamma-ray absorption events in the detector. The pulse shape is used to identify neutron and gamma-ray events. The Ce:LiCAF scintillator has a considerably fast luminescence component only for gamma-ray-induced events.[4,5] This fast luminescence component is due to Cherenkov radiation generated by fast electrons induced with gamma-ray interactions and is not observed in neutron-induced events.[6,7] In addition, the slow luminescence component in the neutron-induced Ce:LiCAF scintillation is larger than that in the gamma-ray-induced scintillation. Figure 2 shows the difference in the slow luminescence component for neutron- and gamma-ray-induced Ce:LiCAF scintillation. These signal time profiles were measured by a fast digitizer (Agilent, U1071A, 2 GS/s, 8 bit) directly connected with the PMT anode. We can identify neutron and gamma-ray events using these differences in signal pulse shape. The detector has a USB port to connect to a personal computer and to transfer measured data. Figure 3 shows an example of the measured data, which can be shown on a personal computer. This figure shows the two-dimensional plot for pulse height versus the pulse shape discrimination index. The pulse shape discrimination index reflects the contribution of the slow luminescence component. In this figure, neutron and gamma-ray events are separately distributed with different pulse height and pulse shape discrimination index ratios. Only neutron events can be selectively counted using this two-dimensional plot. The detector has a display panel to show the selected neutron count rate. The weight of the detector including the battery is 800 g, which is significantly less than that of the conventional portable neutron detector, which weighs more than 5 kg. The portability of the fabricated detector is significantly improved.

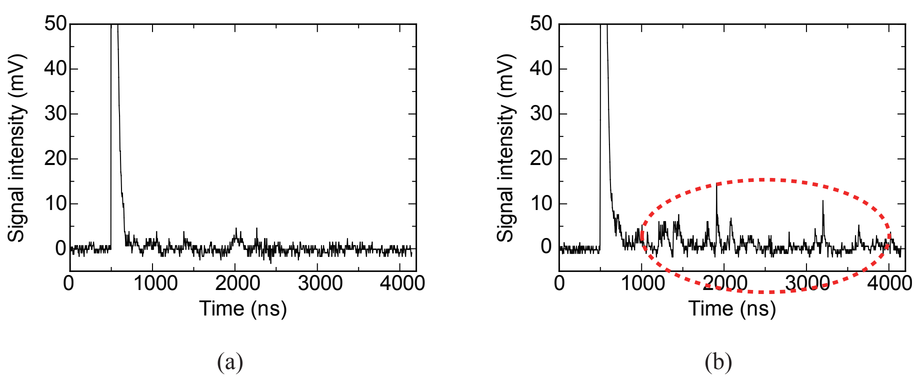


Fig. 2. (Color online) Difference of the slow luminescence component in (a) gamma-ray- and (b) neutron-induced Ce:LiCAF scintillation.

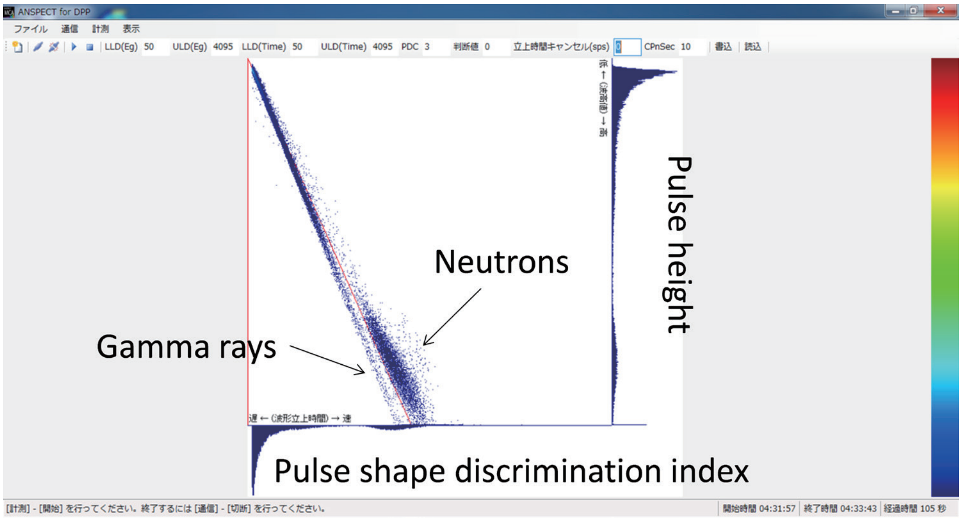


Fig. 3. (Color online) Example of the measured data, which can be shown on a personal computer. This figure shows the two-dimensional plot between the pulse height and the pulse shape discrimination index.

3. Performance Evaluation

First, we evaluated the neutron sensitivity. In this test, a ^{252}Cf neutron source with a neutron emission yield of 1.95 × 10^5 n/s was used. The ^{252}Cf source was placed 2 m away from the detector surface and surrounded by 5 mm Pb shielding and a 25 mm polyethylene moderator. Figure 4(a) shows the schematic drawing of the experimental setup used for neutron sensitivity evaluation. The recorded count was 4396 for 4330 s measurement time, and the neutron count rate was derived to be 1.0 counts per second (cps). At the same detector position, the conventional portable neutron Sievert counter (Aloka, TPS-451BS) weighing 9 kg recorded 0.55 cps. Although the sensitivity of the conventional detector is 1.3 cps/(μSv/h), that of the fabricated prototype is evaluated to be 2.3 cps/(μSv/h). Although the fabricated neutron detector is significantly lighter than the conventional one, it has comparable neutron sensitivity.

As evaluation of gamma-ray suppression ability, the gamma-ray intrinsic detection efficiency, which is defined as the ratio of the measured count of gamma-ray events to the number of incident gamma rays on the detector, was evaluated. A ^{60}Co gamma-ray source with 2.1 × 10^5 Bq was used in this evaluation. Figure 4(b) shows the schematic drawing of the experimental setup used for the gamma-ray detection efficiency evaluation. The source was placed 10 cm away from the detector surface. In this situation, the incident gamma-ray rate was 8.9 × 10^3 gammas/s. The recorded count

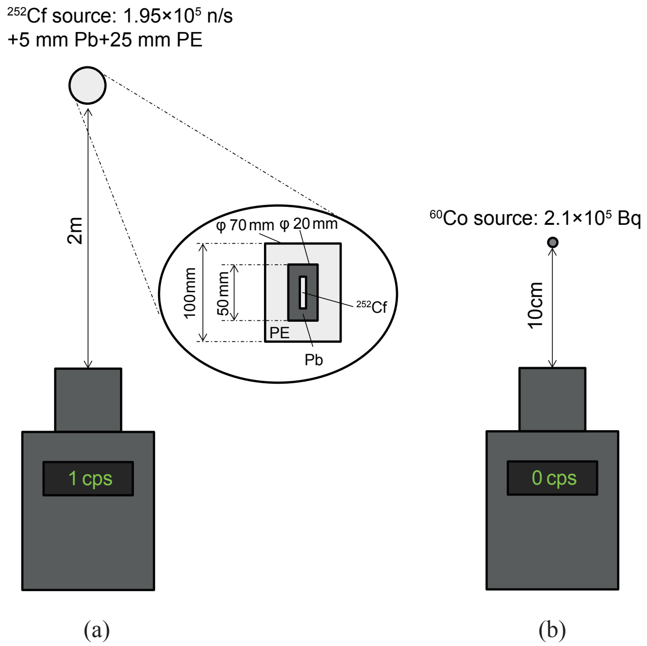


Fig. 4. (Color online) Schematic drawings of the experimental setup for (a) neutron sensitivity evaluation and (b) gamma-ray detection efficiency evaluation.

was 62 for a 3000 s measurement, and the count rate was 0.020 cps. On the other hand, the background count was 43 for 2520 s and the background count rate was 0.017 cps. Therefore, the net count rate is derived to be $(3.6 \pm 3.7) \times 10^{-3}$ cps. The gamma-ray intrinsic detection efficiency is consequently evaluated to be $(4.1 \pm 4.2) \times 10^{-7}$. Although the uncertainty in the evaluated value is relatively large, the gamma-ray intrinsic detection efficiency is confirmed to be on the order of 10^{-6} or less.

Since the speed of the digital signal processor used in the fabricated detector was not high, we checked the values under a high count rate situation. A problem in error counting due to the pile-up effect of gamma-ray-induced events was anticipated. We measured the count rate of error counting under various count rate conditions. In order to change the count rate condition, the distance between the gamma-ray source and the detector was changed from 0 to 10 cm. Figure 5 shows the dependence of the count rate of error counting due to pile-up events on the incident gamma-ray rate. At the incident gamma-ray rate of 10^4 gammas/s, the count rate of error counting is 0.02 cps, which is comparable to the background count rate. We conclude that the fabricated neutron detector can be operated without gamma-ray interference under ordinary conditions with the incident gamma-ray rate less than 10^4 gammas/s.

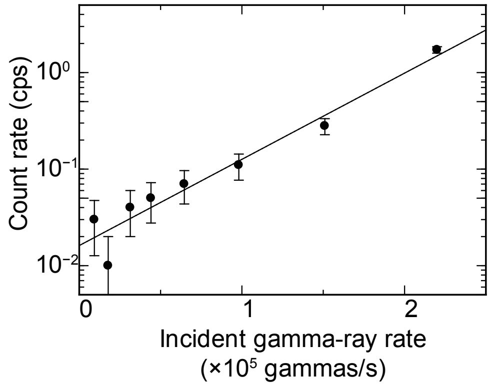


Fig. 5. Dependence of the count rate of error counting due to pile-up events on the incident gamma-ray rate.

4. Conclusion

We fabricated a prototype portable neutron detector using a Ce:LiCAF scintillator. The basic performance was evaluated through basic experiments. The neutron sensitivity of the fabricated detector was evaluated to be 2.3 cps/(μSv/h). Although the fabricated detector weighs only 800 g and is significantly lighter than the conventional neutron Sievert counter with a heavy moderator, the neutron sensitivity is comparable to that of the conventional detector. The gamma-ray intrinsic detection efficiency was evaluated to be less than 10^{-6}. The gamma-ray sensitivity is sufficiently low under ordinary conditions. Under an intense gamma-ray field, the fabricated detector might suffer from error counting due to the pile-up effect of gamma-ray-induced events. The expected count rate of error counting was confirmed to be less than the background count rate for an incident gamma-ray rate of less than 10^4 gammas/s. We conclude that the fabricated portable neutron detector exhibited some excellent properties, such as light weight, high sensitivity to neutrons, and insensitivity to gamma rays.

Acknowledgements

This study is a part of the results of "Development of high efficiency neutron scintillator for thermal and epi-thermal neutrons" carried out under the Development of Systems and Technology for Advanced Measurement and Analysis by Japan Science and Technology Agency. This work was partially supported by the SPRITS program, Kyoto University, and the Cooperative Research Project of Research Institute of Electronics, Shizuoka University. This study is partially supported by the Cooperative Research Project of Research Institute of Electronics, Shizuoka University.

References

1 R. T. Kouzes: The ^{3}He Supply Problem, PNNL-18388 (2009).
2 R. T. Kouzes, J. H. Ely, L. E. Erikson, W. J. Kernan, A. T. Lintereur, E. R. Siciliano, D. L. Stephens, D. C. Stromswold, R. M .V. Ginhoven and M. L. Woodring: Nucl. Instr. Methods Phys. Res., Sect. A **623** (2010) 1035.
3 A. Yoshikawa, T. Yanagida, Y. Yokota, N. Kawaguchi, S. Ishizu, K. Fukuda, T. Suyama, K. J. Kim, J. Pejchal, M. Nikl, K. Watanabe, M. Miyake, M. Baba and K. Kamada: IEEE Trans. Nucl. Sci. **56** (2009) 3796.
4 A. Yamazaki, K. Watanabe, A. Uritani, T. Iguchi, N. Kawaguchi, T. Yanagida, Y. Fujimoto, Y. Yokota, K. Kamada, K. Fukuda, T. Suyama and A. Yoshikawa: Nucl. Instr. Methods Phys. Res., Sect. A **652** (2011) 435.
5 K. Watanabe, Y. Kondo, A. Yamazaki, A. Uritani, T. Iguchi, N. Kawaguchi, K. Fukuda, S. Ishidu, T. Yanagida, Y. Fujimoto and A. Yoshikawa: IEEE Trans. Nucl. Sci. **60** (2013) 959.
6 M. Koshimizu, T. Yanagida, Y. Fujimoto, A. Yamazaki, K. Watanabe, A. Uritani, K. Fukuda, N. Kawaguchi, S. Kishimoto and K. Asai: Appl. Phys. Exp. **6** (2013) 062601.
7 K. Watanabe, Y. Kondo, A. Yamazaki, A. Uritani, T. Iguchi, N. Kawaguchi, K. Fukuda, S. Ishidu, T. Yanagida, Y. Fujimoto and A. Yoshikawa: Radiat. Meas. **71** (2014) 158.