Nuclear Instruments and Methods in Physics Research A 832 (2016) 21–23

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Technical notes

An application of CCD read-out technique to neutron distribution measurement using the self-activation method with a CsI scintillator plate

Akihiro Nohtomi [a,*], Ryosuke Kurihara [a], Hiroyuki Kinoshita [a], Soichiro Honda [a], Masaaki Tokunaga [a], Heita Uno [a], Kiyomitsu Shinsho [b], Genichiro Wakabayashi [c], Yusuke Koba [d], Junichi Fukunaga [e], Yoshiyuki Umezu [e], Yasuhiko Nakamura [e], Saiji Ohga [f]

[a] Graduate School of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan
[b] Graduate School of Human Sciences, Tokyo Metropolitan University, 7-2-10 Higashi-oku, Arakawa-ku, Tokyo 116-8551, Japan
[c] Atomic Energy Research Institute, Kinki University, 3-4-1 Kowakae, Higashiosaka-shi, Osaka 577-8502, Japan
[d] National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage-ku, Chiba-shi, Chiba 263-8555, Japan
[e] Department of Radiology, Kyushu University Hospital, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan
[f] Department of Clinical Radiology, Graduate School of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan

ARTICLE INFO

Article history:
Received 13 March 2016
Accepted 14 June 2016
Available online 15 June 2016

Keywords:
The self-activation method
CCD read-out
CsI scintillator plate
Neutron distribution measurement
Photo neutrons
Decay fitting

ABSTRACT

In our previous paper, the self-activation of an NaI scintillator had been successfully utilized for detecting photo-neutrons around a high-energy X-ray radiotherapy machine; individual optical pulses from the self-activated scintillator are read-out by photo sensors such as a photomultiplier tube (PMT). In the present work, preliminary observations have been performed in order to apply a direct CCD read-out technique to the self-activation method with a CsI scintillator plate using a Pu-Be source and a 10-MV linac. In conclusion, it has been revealed that the CCD read-out technique is applicable to neutron measurement around a high-energy X-ray radiotherapy machine with the self-activation of a CsI plate. Such application may provide a possibility of novel method for simple neutron dose-distribution measurement.

The goal of radiation cancer therapy is to deliver adequate dose to tumor, while keeping the dose of normal tissues to a minimum. In order to achieve this “conformal radiation therapy”, various techniques have been developed, such as modern “Intensity Modulated Radiation Therapy” with X-rays. On the other hand, however, photo-neutron generation from high-energy medical X-ray linac is often controversial issue, because that has a potential to increase the risk of second cancer [1]. Such photo neutrons chiefly originate from the X-ray beam blocking by high-Z materials of target and collimators [2].

For monitoring such rather weak neutron field, we have recently proposed a novel dose monitoring method using the self-activation of iodine-containing scintillators [3,4]. In the proposed method, beta-rays from an NaI scintillator had been successfully utilized for detecting neutrons around a high-energy X-ray radiotherapy machine; individual beta-ray pulses from the self-activated NaI scintillator are read-out by photo sensors such as a photomultiplier tube (PMT). In the present work, preliminary observations have been performed in order to apply a direct CCD read-out technique to the self-activation method with a CsI scintillator plate. Differing from an NaI crystal, a CsI plate is practically usable without a particular cover owing to its low deliquescence.

A read-out test was conducted by using a Pu-Be neutron source (3.7×10^{11} Bq, mean neutron energy $\sim$4 MeV) at Atomic Energy Research Institute, Kinki University. Low energy neutrons filtered by a cylindrical polyethylene (P.E.) moderator (20 cm $\phi \times$ 20 cm h) were irradiated to an uncovered CsI plate ($50 \times 50 \times 2$ mm^3) for 75 min as shown in Fig. 1. Thermal neutron fluence rate at the field was estimated to be $\sim$500 (n/cm^2/s) by another Au foil activation method. A Cd disk (10 mm $\phi \times$ 1 mm t) was put on the center of surface of the CsI plate. During irradiation, the CsI plate was kept in a thin shading bag for avoiding the influence of ambient light. After the termination of irradiation, the CsI plate was arranged in a black box and viewed by a cooling type CCD camera (Atik 383L+) [5]; luminance distribution on the plate was recorded every 1 min or 10 min as 16 bit JPEG image through the USB interface. After that, those images were analyzed by a software “ImageJ” [6] to obtain the time variation of mean pixel values in the specified

* Corresponding author.
E-mail address: nohtomi@hs.med.kyushu-u.ac.jp (A. Nohtomi).

http://dx.doi.org/10.1016/j.nima.2016.06.078
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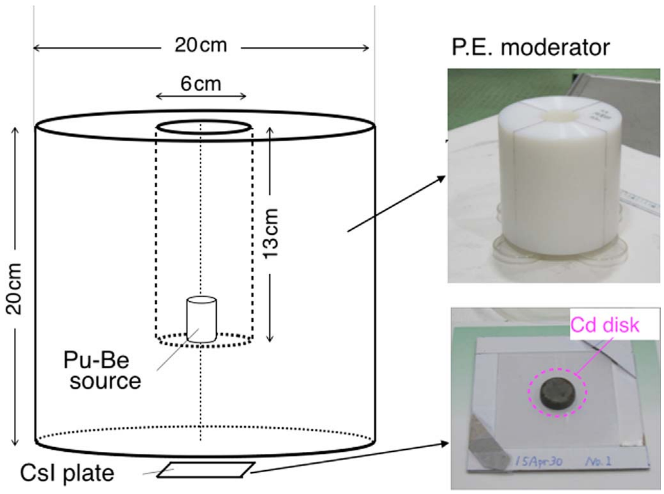

Fig. 1. Experimental arrangement for Pu-Be irradiation.

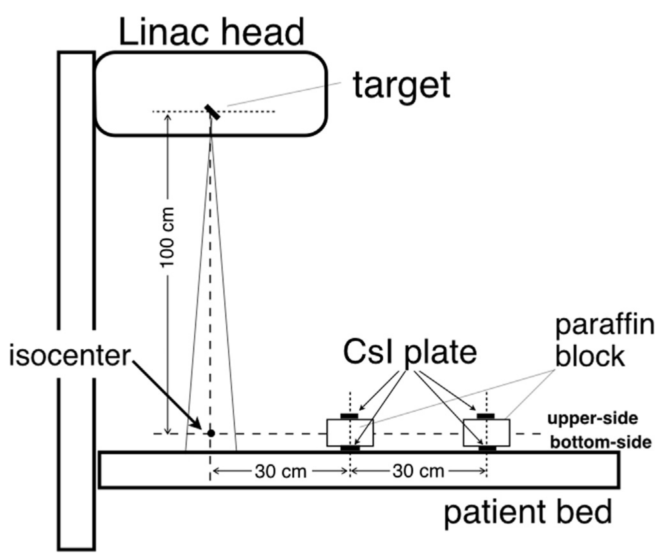

Fig. 2. Experimental arrangement for linac irradiation.

"region of interested (ROI)".

As a demonstration to check its technical feasibility, additional measurement was also attempted in a linac field. Four small CsI plates ($20 \times 20 \times 2$ mm^3) were simultaneously irradiated at a 10-MV linac (Varian Clinac 21EX) of Kyushu University Hospital. The operational condition was the same as previous one used in Ref. [3]: i.e. 30 min irradiation with a primary field size of 40×9 cm^2 (so called "total body irradiation" condition) and a dose rate of 3 Gy/min at the isocenter position. The experimental layout is given in Fig. 2. Four CsI plates were arranged at 30 cm and 60 cm from the isocenter on the upper-side and the bottom-side of a paraffin block ($20 \times 10 \times 5$ cm^3) which contains 5–10% B_2O_3 for neutron shielding; shading bags were also used for avoiding the influence of ambient light during irradiation. After the termination of irradiation, the four CsI plates were simultaneously arranged in a black box and viewed by the CCD camera (Atik 383L+); JPEG images were recorded every 1 min in the same manner as the Pu-Be irradiation mentioned already.

Fig. 3 shows time variations of the luminance which was read-out every 10 min from the self-activated CsI for Pu-Be irradiation. In the inset of Fig. 3, a darkened area is clearly visible in its center part, which corresponds to the Cd disk. Two ROIs are set to different circle regions where the Cd disk exists [A] and does not [B]. Vertical luminance axis is expressed by a mean pixel value of each

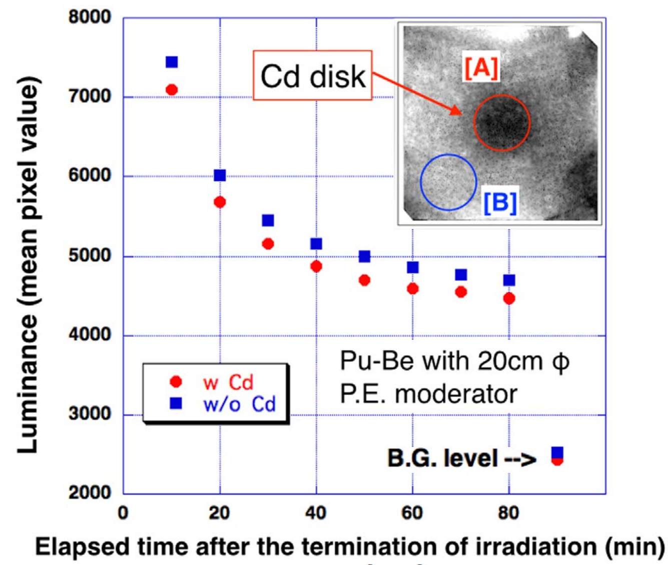

Fig. 3. Time variations of luminance read-out every 10 min from the self-activated CsI plate by Pu-Be for different ROI settings: [A] with a Cd disk and [B] without a Cd disk.

ROI. Two plots for different ROIs indicate similar time behavior. The luminance of region with Cd disk ([A], circle symbol) is lower than that without Cd disk ([B], square symbol); the difference between both curves may correspond to a contribution of thermal neutron component.

Another similar decay curve of luminance from the self-activated CsI plate by Pu-Be was obtained for every 1 min read-out as displayed in Fig. 4. A Cd disk was not applied and a square ROI was set to the nearly entire region of 5×5 cm^2. Decaying components included in the curve were analyzed by fitting it with possible time constants using least-square method. As the result, Cs-134m (half life $T_{1/2} = 174$ min) component was identified [7] as well as I-128 (half life $T_{1/2} = 25$ min) and a constant background (B.G.) components. In addition, a quickly-decaying component (half life $T_{1/2} \sim 1.6$ min) was also found as residual. Such component is

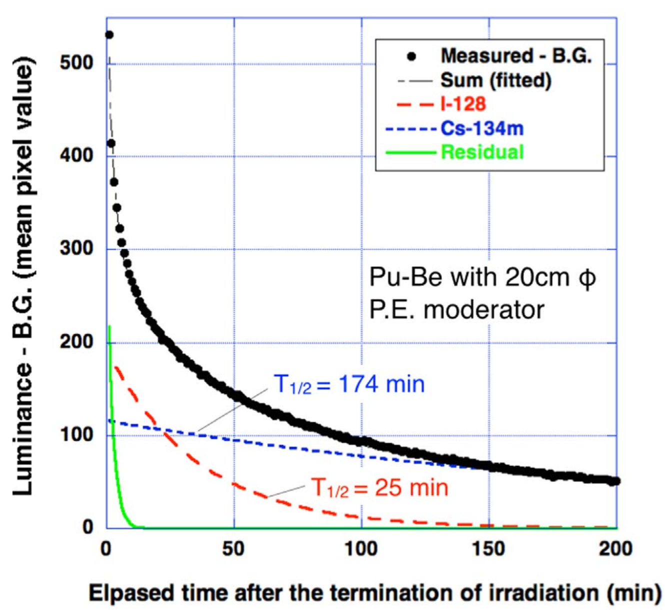

Fig. 4. Time variation of luminance read-out every 1 min from the self-activated CsI by Pu-Be. A Cd disk was not used and a ROI was set to the nearly entire region of 5 cm $\times$ 5 cm. The constant B.G. component has been already subtracted.

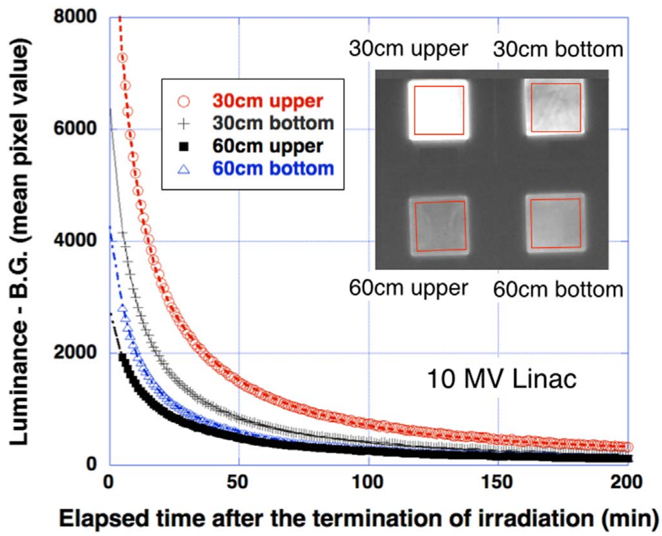

Fig. 5. Time variations of luminance read-out every 1 min from the self-activated four CsI plates by 10 MV linac. The constant B.G. components have been already subtracted. ROI settings for four CsI plates are indicated in the inset.

Table 1
Initial luminance values for I-128 and Cs-134m just after the termination of irradiation for different locations.

	30 cm-upper	30 cm-bottom	60 cm-upper	60 cm-bottom
I-128	3769	2161	1159	1525
Cs-134m	697	388	246	273

attributable to an afterglow of primary radiations. The equation of fitting curves is given in Eq. (1): correlation coefficient R = 0.9995.

$$Luminance = 192 \times (1/2)^{t/25} + 116 \times (1/2)^{t/174} + 339 \times (1/2)^{t/1.55} + 1911,\ t \text{ in min} \quad (1)$$

Please note that the constant B.G. component has been already subtracted in Fig. 4.

In the additional measurement at a 10 MV linac, four small CsI plates were simultaneously viewed by the CCD camera and four decay curves were derived for different ROI settings (i.e. for different neutron fields) as shown in Fig. 5. Decaying components included in those curves were analyzed in the same manner applied in Fig. 4. As the result, those curves can be commonly fitted well with I-128, Cs-134m, B.G. and the quickly-decaying residual components. By this, the initial luminance values just after the termination of irradiation had been evaluated for I-128 and Cs-134m as shown in Table 1.

In Figs. 3–5, time variations of optical signals emitted from a self-activated CsI scintillator plate are recorded as electric charge in CCD elements; discrimination setting for individual pulse height is not available for read-out. Therefore, all optical signals including B.G. components contribute to the charge integrated in a certain time period. In this data treatment, energy spectra of radiations (beta-rays, conversion electrons and gamma-rays) emitted from the self-activation of CsI are not observable because pulse measurement of each radiation is not allowed. On the other hand, obtained decay curves of luminance can be fitted well with common exponential components of known decay constants for I-128 and Cs-134m. So, contributions from different radioisotopes can be evaluated separately on the basis of time variation and, consequently, quantitative discussion becomes available.

The decay curves mentioned above do not provide direct information on absolute value of radioactivity because the measurement is based on the detection of integrated charges of different pulses, not a charge of individual pulse. So, in principle, that is merely a relative measurement and a careful calibration is essential for more detailed discussions. However, such method may be practically applicable to a simple dose-distribution measurement because a CCD-camera is capable of easily imaging by a single read-out. Moreover, in this method, differing from other passive imaging devices, no particular process is required for image read-out, such as laser stimulation for imaging plates [8] or heating for thermo-luminescence dosimeters [9].

As actual application, there are two possible choices for neutron distribution measurement: (1) using a wide CsI plate like Figs. 3, 4 and (2) using several small CsI plates positioned at several locations like Fig. 5. In addition, individual responses of I-128 and Cs-134m components must provide useful information on neutron energy, because their cross sections of generation have different dependencies on neutron energy. By reflecting this situation, for Pu-Be irradiation in Fig. 4, the ratio of initial luminance values between I-128 and Cs-134m is 192/116 = 1.7, while the values are 4.7–5.6 for linac irradiation in Fig. 5 and Table 1. Such difference may come from different neutron energy spectra of the two fields.

In the present work, through preliminary observations using a Pu-Be neutron source and a 10-MV linac, it has been revealed that the CCD read-out technique is applicable to neutron measurement around a high-energy X-ray radiotherapy machine with the self-activation of a CsI plate. There are several advantages when that is used for QA purposes in terms of time saving. In conclusion, CCD read-out technique with the self-activation of a CsI plate may provide a possibility of novel method for simple neutron dose-distribution measurement that is practical in a hospital. Further developmental work is now planning for this aspect.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

This study was performed in part under the Cooperative Research at Kinki University Reactor supported by the Graduate School of Engineering, Osaka University. The authors thank Miss Ryoko Matsuo and Mr. Ryo Kakino of the Department of Health Sciences, Kyushu University for their cooperation in this study.

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