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Applicable Prospects of Flexible Radiation Detectors Using Liquid Scintillation Light Guide (LSLG)

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Abstract

TEPCO's Fukushima Daiichi Nuclear Power Plant accident resulting from the Great East Japan Earthquake and Tsunami (11th March 2011) brought radioactive materials in wide area such as soils, forests, roofs of houses and cars, and so on. Radioactive materials released were accumulated on local sites such as mountain foot, side ditch and pond by wind and rain. It was difficult to identify contaminated spots such as side grooves, and drain pipes by conventional radiation counters, especially in non-uniform irradiation field, Here, if there is one portable and flexible detector, it is convenient to measure easily various kinds of samples and radiation fields irrespective of accuracy. Considering that it is relatively easy to handle various kinds of measurements, the development of a flexible radiation detector is required.

Introduction

On the other hand, a radiation detector using Plastic Scintillation Fibers (PSF) has been developed since 1980's for high energy physics experiments [1,2]. The flexible PSF itself is bundled by many fine fibers of 1 mm in maximum diameter to detect the radiation effectively [3]. The PSF detector connects two Photomultiplier Tubes (PMT) to both ends of the PSF, and specifies the position of the spot radiation according to the time difference or the emission amount ratio of the arriving light. Using the 20 m PSF detector JAEA measured the radioactivity of ground and at bottom of pond after the nuclear power plant accident at Fukushima [4].

The idea that liquid scintillator could be used as core material in tube was also proposed in the previous review, but it has not been enough realized yet [2].

We have developed a flexible radiation detector using a Liquid Scintillation Light Guide (LSLG) and a single PMT [5]. The LSLG detector was also introduced as short communication in the journal of Dental & Craniofacial Research [6]. The applicable prospects of flexible liquid detectors are reviewed here with the characteristics of an LSLG detector.

Characteristics of LSLG Detector

The Liquid Light Guide (LLG) would be also flexible in shape and could enlarge the tube diameter. Characteristics of LLG with 5 mm in diameter were studied as the position sensitive detector by detecting Cherenkov light due to neutron [7]. The γ irradiation effect of C_o-60 on the light transmission of LLG was also investigated to discriminate from neutron detection, and the light transmission loss was not so observed at dose of 2.5 kGy, whereas the light transmission loss rate of the PSF was over 90%. In addition, even when the LLG including scintillator was irradiated by γ rays with high dose of 1.5 kGy × 10 kGy, no light transmission loss was observed [8].

By the way, liquid scintillation counters are routinely used for measuring β emitting nuclei in a sample mixed with scintillation cocktail. Coincidence counting system with two PMTs is used to reduce the influence of external radiation. A liquid scintillation has not been enough applied for measuring the external radiation as a γ ray detector. Luminescence of liquid scintillation is generated by the electrons produced by Compton scattering of γ rays. Since the density of liquid scintillation is close to the density of water, it can be applied to dosimeters equivalent to tissue.

The characteristics of 3 m LSLG with 8 mm in inner diameter are described as a typical example. The luminescent properties of LSLG (UG30) are similar to those of the improved Kuraray's PSF as follows; SCSF-81 (Blue wave length: 437 nm, decay time: 2.4 ns, attenuation length: >3.5 m). The diameter of LSLG tube is so larger than PSF itself that the detection efficiency can increase and the light transmission loss of LSLG can be small by using the dilute scintillator.

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Figure 1(a)

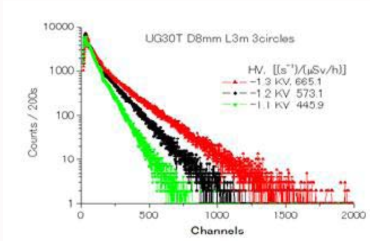

Figure 1(b)

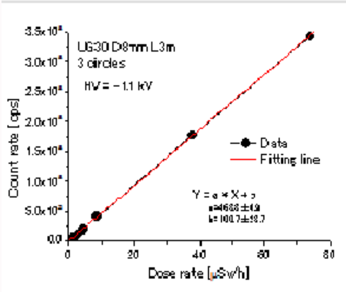

Figure 1(c)

Figure 1: (a) Picture of 3m LSLG (30% UG, Diameter = 8 mm) with 3 circles; (b) PHA spectra in log scale (applied voltages (HV) of PM: -1100V, -1200V and -1300V, γ ray source: Cs-137) and (c) the relationship between dose rates and integral count rates of LSLG [5].

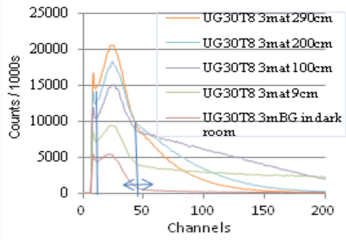

Figure 2(a)

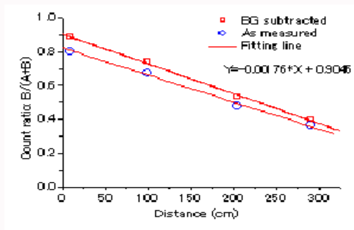

Figure 2(b)

Figure 2: (a) PHA spectra in linear scale; (b) the relationship between irradiation points (distance from PMT head) and integral count ratios of B/(A+B) in PHA [5].

Since the light emission lifetime of liquid scintillator is several nanoseconds, the LSLG detector can measure radiation with a high counting rate as shown in Figure 1. The characteristics of LSLG detector are summarized in Table 1. By using a fast amplifier, high absorption dose rates (>80 μSv/h) can be measured since the decay time is several ns. The circular type of LSLG detector can be used as a dosimeter. The scintillator concentration, thickness and length of the inner tube can be easily adjusted according to the intended usage. Since the energy resolution of liquid scintillator is poor, it is unsuitable for analysis of nuclides, but its drawback can be compensated by the followings; A solid scintillator such as CsI crystal is attached to the tip of light fibers as a hybrid detector or a Phoswich scintillation detector to discriminate each signal because solid state scintillator and liquid scintillator have different emission characteristics in lifetime and wavelength of light emission.

As shown in Figure 2, the LSLG detector can be also used as a position sensitive detector. Since the radiation detector be long and bent freely, we could measure contaminated activity in a narrow place, or by setting just surround the samples such as living trees, logged timber, cereals, vegetables, and food items. For example, if a sample to be measured is placed at the center of a flexible detector with circular shapes, the radioactivity can be easily estimated after the weight is measured although the outer radiation shield may be necessary. Also, it is possible to detect the contamination spots of buried piped and drain pipes etc. using a linear relationship between the count ratios of two divided regions in Pulse Height Analyzed (PHA) spectra and the distance of contaminated spots from a PMT head [5]. The slope of the linear relationship is easily adjusted by the concentration of the liquid scintillator. The changed PHA spectra might be analyzed using artificial intelligent technique in future. A long flexible detector would be useful as a room monitor in high dose radiation controlled area such as nuclear and radiation facilities of accelerators.

As a further application of flexible detectors, a flat type detector would be easily constructed by aligning many flexible tubes in plain, or by making the detector a mat. Flexible flat detector allows us to measure the radiation of human being, livestock and wildlife. In other words, it can be placed on the back of livestock and animals that are difficult to be stationary. A best wear type flexible flat detector would be able to estimate the scattering radiation dose for radiotherapy patient. They can be called a wearable detector.

Development of an Absorption Dosimeter Equivalent to Human Tissue

A response of conventional solid state detectors has large dependence on radiation energy. A liquid detector that is nearly equivalent to human tissue is considered to be suitable for direct

Table 1: Characteristics and applications of Liquid Scintillation Light Guide (LSLG).

1. Fluorescence lifetime of liquid scintillation (several ns).	Absorption dose meter with a wide dynamic range.
2. Dependence of PHA spectrum on irradiation points.	Position sensitive long detector.
3. Light attenuation length can be easily changed, depending the concentration of liquid scintillator.	Long flexible detector for room monitor and tube monitor.
4. Circular flexible LSLG.	Survey meter for wide surface area and space dosimeters.
5. Flexible flat detector with aligned tubes or a plat pad.	Wearable detector.
6. γ rays emitter nuclides were hardly discriminated (disadvantage).	A solid state scintillator is installed with light fiber cable or at end of liquid light guide tube. Hybrid scintillation detector. Phoswich detector.

measurement of absorbed doses since about 65% of the human body is composed of water. It would be applicable to estimation of dose rate in high radiation fields as well as medical fields.

That is, flexible liquid detectors could directly evaluate the influence of radiation irradiation for diagnosis and therapy, and the dental and medical applications would be greatly expected although the further study is necessary. For example, the protective tube needs to be changed according to the energy of the radiation used.

Conclusion

Flexible detectors can be used as position sensitive detectors for non-uniform radiation and as absorbed dose rate meters for any shape sample. Liquid scintillation detectors have not been enough developed so far because the energy resolution is poor. However, an LSLG detector may be superior to conventional solid state detectors in less radiation damage for high radiation dose rates. An LSLG detector could be used as a tissue equivalent absorbed dosimeter. A flexible flat LSLG detector would easily measure the radiation dose for human beings with various sizes and shapes. It is important that flexible liquid detectors are newly developed from the viewpoint of absorbed dose estimation for human beings. By setting the circular shape of LSLG, the absorbed dose of normal tissue due to scattered radiation could be directly evaluated in radiotherapy or diagnosis.

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