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Performance of a plastic scintillator and GM pancake tubes as alpha and beta contamination detectors in dosimetric stand

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Abstract. A model of detection probe with a plastic scintillator (230 × 105 × 1 mm^3) with a ZnS(Ag) layer at the top, and a model with six pancake Geiger-Müller (GM) counters were investigated as alpha particles (Am-241) and beta radiation (Sr-90) contamination detection probes at a dosimetric stand. A detection probe, 166 × 104 mm^2 of active area, with a proportional counter was also investigated for comparison. The scintillation probe showed a higher alpha detection efficiency and a comparable beta detection efficiency with respect to the probe containing the proportional counter. The GM probe shoved a higher alpha detection efficiency, and a lower beta detection efficiency than the proportional counter probe. Detection efficiency of the scintillation probe strongly depends on the distance from the photomultiplier tube (PMT) photocathode. Active area of the GM probe of all counters constitutes approximately 50% of its measuring area.

Key words: dosimetric stand • detection system • GM counter • plastic scintillator

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Introduction

For measurement of hand and foot contamination with radioactive nuclides, detection probes with proportional counters are widely used. An example of such application is a whole body dosimetric stand [1] where 15 detection probes with proportional counters are used. A proportional counter shows a good detection efficiency, and practically the same sensitivity to radioactive contamination across its active measuring surface, but the counter is a costly one. Beside that, when the delicate counter window is broken for some reason, which may happen in a dosimetric stand, or the counter looses its gas tightness, the counter has to be replaced with another one, or at least repaired. Repair of the proportional counter is an expensive operation. Due to these reasons, a tendency to use plastic scintillation detectors in place of proportional counter can be observed [2–4, 7]. An advantage of a scintillation detector is a large active area of such a detector and its simultaneously high detection efficiency. A plastic scintillator in the form of a thin sheet (foil) is a convenient detector for alpha, beta, and gamma radiation and is relatively cheap. When the aluminized foil of the measuring window of a scintillation probe is mechanically damaged, it can be easily and cheaply repaired. To increase sensitivity for alpha radiation, plastic scintillators are frequently covered with a thin layer of zinc sulfide ZnS(Ag). ZnS(Ag) is deposited directly at the top of plastic scintillator, or a thin foil covered with ZnS(Ag) is added at the top of plastic scintillator.

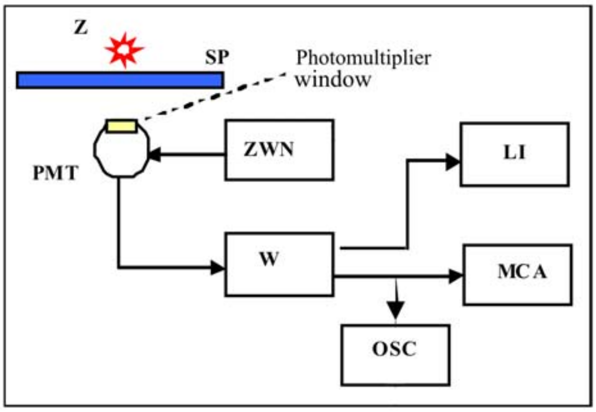

Fig. 1. Measuring circuit of the detection probe. Z – radiation source; PMT – photomultiplier tube; SP – plastic scintillator + ZnS(Ag); W – pulse amplifier + pulse discriminator; LI – pulse counter; OSC – oscilloscope; ZWN – high voltage power supply; MCA – multichannel analyzer.

Other promising detector of radioactive pollution, although rarely used in dosimetric stands, is a "pancake", window GM detector. This detector is equipped with a mica window allowing measurement of alpha, beta and gamma radiation. A model of detection probe containing a few "pancake" GM counters was also a subject of investigations. Models of the detection probes were developed and investigated. The results of investigations of both models are presented in the paper. Additionally, for comparison, investigations were carried out of an existing detection probe with a proportional counter.

Scintillation probe

The used model of a scintillation detection probe was in the form of a light, tight rectangular parallelepiped, containing a plastic scintillator 250 × 125 × 1 mm^3 at the top of which a semitransparent foil 250 × 125 × 0.1 mm^3, with deposited ZnS(Ag) zinc sulfide, was placed. Two layers of an aluminized foil made a light tight measuring window. Below the scintillator, in the middle of its longer side, a light collimator and a photomultiplier tube with a side window 8 × 24 mm^2 are placed. The probe contained a high voltage power supply, a pulse amplifier and a pulse discriminator. The measuring circuit of the probe is shown in Fig. 1. Points of irradiation of the probe (scintillator) by an alpha particles source (Am-241, active diameter 49 mm), and by a beta radiation source (Sr-90, active diameter 36 mm) are shown in Fig. 2. The Sr-90 source was in radiation equilibrium with Y-90.

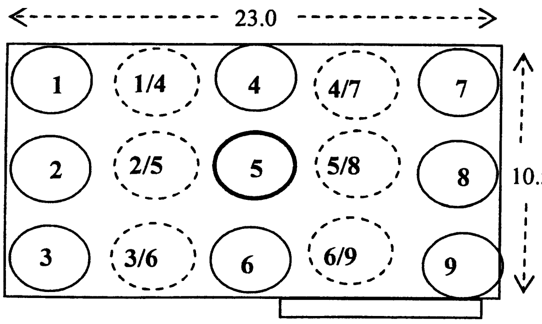

Fig. 2. Irradiation points of the probe (dimensions given in cm).

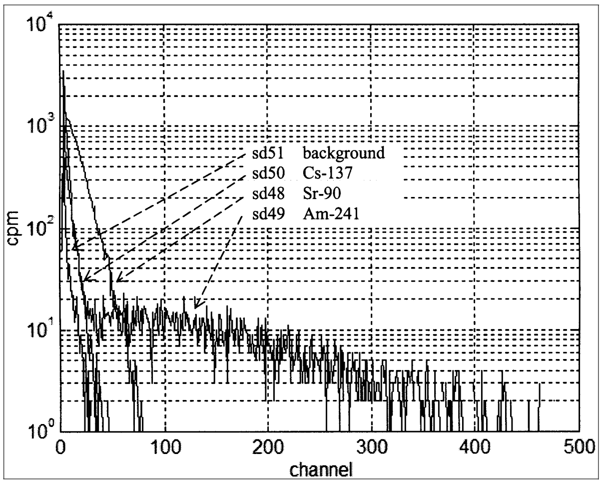

Fig. 3. Differential radiation spectra of background, alpha (Am-241), beta (Sr-90), and gamma (Cs-137) measured with a plastic scintillator + ZnS(Ag) phosphor.

In Fig. 3 the differential spectra of background, alpha, beta and gamma radiation are shown when point 5 of the scintillator was irradiated. When investigating the detection efficiency of gamma radiation, the whole probe was irradiated with a Cs-137 point source from some distance. It can be seen from Fig. 3 that the Am-241 spectrum, detected by the ZnS(Ag) scintillator, differs considerably from the other spectra detected by the plastic scintillator.

Detection efficiency of radiation was determined from pulse count rate when the scintillator was irradiated in different points, after correction for background. Detection efficiency varies depending on the distance of the irradiated scintillator fragment from PMT photocathode, on discrimination level (background) and on radiation type. At discrimination level corresponding to a background count rate of 10 cps, the detection efficiency for alpha radiation, along the axis 2-2/5-5-5/8-8 varies from 0.42 cps/Bq at the center to 0.25 cps/Bq at the edges of the scintillator. The average detection efficiency for five measuring points is 0.32 cps/Bq. The beta detection efficiency varies from 0.37 to 0.09 cps/Bq, at an average detection efficiency of 0.19 cps/Bq for five measuring points. Variation of the detection efficiency depending on irradiated scintillator fragment is high, particularly for beta radiation.

Detection efficiency of gamma radiation was determined by measuring pulse count rate when the whole probe was irradiated by a point Cs-137 source from some distance, after background correction was made. The achieved gamma detection efficiency is 0.0023 cps/Bq, and the minimum detectable activity (MDA) for gamma is 6.4 Bq/cm^2.

The MDA of contamination, corresponding to unit area of measuring probe surface, was determined from the relation [6]:

$$\text{(1)} \qquad \text{MDA} = 3.29k\sqrt{n_b\left(\frac{1}{t_b} + \frac{1}{t_s}\right)} \quad (\text{Bq}/\text{cm}^2)$$

where: $k = (\varepsilon p)^{-1}$ (Bq/cm^2)/cps – calibration coefficient; ε (cps/Bq) – average detection efficiency; p (cm^2) – probe measuring area; n_b (cps) – background count rate; t_b – background counting time = 60 s; t_s – signal counting time = 10 s.

In a recommendation [7], the non-uniformity in response to probe irradiation with a small calibration source is accepted without placing any restrictions. PN-EN norm [6] defines the non-uniformity as the ratio of maximum to minimum detection efficiency that should not exceed 2. Non-uniformity of the detection efficiency is the main problem of the plastic scintillation probe, especially for low energy beta radiation. The achieved ratio of max to min beta detection efficiency is approximately 4 at a background count rate of 10 cps. The max to min ratio for alpha radiation is better and is equal to 1.68.

Non-uniformity of the detection efficiency (sensitivity) can be improved by setting a lower discrimination level of the pulses from the PMT output. At a discrimination level resulting in a background count rate of 100 cps, the max/min ratio is close to 2. Decrease of the discrimination level results also in a higher detection efficiency for alpha and beta radiation, that partially compensate the negative influence of background count rate on MDA, and a higher MDA for beta and alpha radiation. Results of measurements and computations for the scintillation probe with a high discrimination level (low background) and a low discrimination level (high background count rate) are given in Table 1.

Thus, to ensure satisfactory uniformity of beta detection efficiency the scintillation probe has to operate at high background pulse count rate. Investigations carried out shoved that alpha detection non-uniformity is satisfactory even at the background count rate less than 0.5 cps. It happens so thanks to the ZnS(Ag) phosphor placed at the top of plastic scintillator showing high light output of the registered alpha particles. The investigations showed also that at 2 cps background count, alpha particles detection efficiency was 0.19 cps/Bq and the smallest MDA for alpha radiation 0.035 Bq/cm^2 can be achieved.

Another way to ensure satisfactory non-uniformity of beta radiation detection efficiency is decreasing plastic scintillator length to 16.5 cm. Calculations indicate that such a shorter detection probe, at a background count rate of 10 cps, will show higher average detection efficiencies and a lower MDA, but the price paid for this is the smaller detecting surface of the probe.

An attempt was made to replace the PMT by a semiconductor scintillation light detector (multi pixel photon counter – MPPC) [5] in the scintillation probe for radioactive contamination measurement. The investigations carried out shoved that the MPPC light detector (high noise, low active area, high sensitivity to ambient temperature) cannot replace satisfactorily the PMT as light detector.

GM detection probe

The investigated detection probe contained 6 window "pancake" GM counters placed side by side in two parallel rows. Active area of the 6 counters was 93.3 cm^2. Outline of GM counters, which is the measuring area of the probe, had the dimensions: 11.3 × 17.2 = 194 cm^2. The GM counters were connected for parallel operation. Pulse discriminator and line driver were incorporated into the probe. The probe was powered from +5 V, and +500 V.

Alpha detection efficiency of GM counters was determined as average detection efficiency of 6 counters when they were irradiated separately, after background correction. The average detection efficiency was found to be equal to 0.458 cps/Bq for alpha radiation, then the effective detection efficiency was calculated for the whole measuring area of the probe 0.458 × 93.3/194 = 0.22 cps/Bq. In a similar way, beta detection efficiency was determined. Gamma radiation detection efficiency was determined from the pulse count rate when the whole probe was irradiated by the Cs-137 point source from some distance. The detection efficiencies are given in Table 1. The max to min ratio of detection efficiency of

Table 1. Comparison of measuring probes

Parameter	Scintillation, low background	Scintillation, high background	GM probe	Proportional probe	Description
					General
n_b (cps)	10	100	5.7	11.6	Background
a_a (cm^2)	241.5	241.5	93.3	173	Probe active area
a_p (cm)	23 × 10.5	23 × 10.5	11.3 × 17.2	16.6 × 10.4	Dimensions of measuring area
USD	625	625	690	1500	Cost of main components
					Alpha radiation, Am-241
ε (cps/Bq)	0.32	0.71	0.22	0.139	Average detection efficiency
Max/Min	1.68	1.67	1.32	1.13	Non-uniformity
k ((Bq/cm^2)/cps)	0.0129	0.0059	0.0234	0.0416	Calibration coefficient
MDA (Bq/cm^2)	0.046	0.066	0.063	0.159	Minimum detectable activity
					Beta radiation, Sr-90
ε (cps/Bq)	0.19	0.37	0.306	0.398	Average detection efficiency
Max/Min	4	2.08	1.05	1.07	Non-uniformity
k ((Bq/cm^2)/cps)	0.022	0.011	0.0168	0.0145	Calibration coefficient
MDA (Bq/cm^2)	0.077	0.126	0.060	0.056	Minimum detectable activity
					Gamma radiation, Cs-137
ε (cps/Bq)	0.0023	0.0065	0.006	0.007	Detection efficiency
k ((Bq/cm^2)/cps)	1.8	0.637	0.86	0.826	Calibration coefficient
MDA (Bq/cm^2)	6.4	7.16	3.05	3.16	Minimum detectable activity

the counters is small and is equal to 1.32 for alpha and 1.05 for beta radiation. Thanks to the low background count rate < 5.7, cps the minimum detectable contamination activity is relatively low, see Table 1.

The main problem of the detection probe with GM counters is the dead area of the probe which is slightly greater (101 cm^2) than the active area of all GM counters (93.3 cm^2). The PN-EN norm [6] specifies that the detection efficiency of area 25 × 25 mm^2 of the probe for surface emission should not be lower than a half of the maximum detection efficiency. In dosimetric gate of the whole body like that in [1] many detection probes are used to monitor radioactive contamination of human being, spaced from each other at some distance. It seems thus reasonable to assume that the dead area of GM probe has no greater significance comparing to the dead space between the probes, and that GM probe can be accepted for such applications.

Proportional counter detection probe

An existing detection probe, that was investigated for comparison, consisted of a xenon proportional counter of active dimensions 16.6 × 10.4 cm^2, equipped with a pulse amplifier, pulse discriminator, and line driver. The probe was powered from an external power supply +1450 V, and ± 12 V.

To determine detection efficiency of alpha and beta radiation, the probe was irradiated in 9 measuring points located in three parallel rows at the probe active surface, the pulse count rate being measured and corrected for background. Detection efficiency at all measuring points was computed, and then the average detection efficiency and the ratio max to min detection efficiency was calculated. To determine gamma detection efficiency, the whole probe was irradiated with the Cs-137 point source from some distance.

The ratio of max to min detection efficiency of beta radiation was found to be 1.13 for alpha and 1.07 for beta radiation. The probe exhibits a good uniformity of sensitivity. The other parameters are given in Table 1.

Comments and conclusions

The main problem of scintillation probe is its strong dependence of non-uniformity of the beta detection efficiency with increasing scintillator size. To keep the non-uniformity of plastic scintillator 23 cm long in permissible limits, a low discrimination level corresponding to background higher than 100 cps has to be set. For such a discrimination level, the MDA of beta radiation is 0.126 Bq/cm^2 that is worse than for the investigated detection probe with a proportional counter 0.056 Bq/cm^2.

Thanks to the ZnS(Ag) phosphor at the top of plastic scintillator, the uniformity of alpha particles detection efficiency is satisfactory at a much higher discrimination level corresponding to the background count rate 0.5 cps. At the discrimination level corresponding to the background count rate 2 cps, the alpha radiation detection efficiency is 0.19 cps/Bq and the MDA for alpha radiation is 0.035 Bq/cm^2. These results are better than the alpha radiation detection efficiency and MDA for alpha radiation that can be achieved in the detection probe with a proportional counter.

Recommended permissible limits of surface contamination in laboratories are 10 Bq/cm^2 for Sr-90, and 0.1 Bq/cm^2 for Am-241 [7]. This means that such a contamination of hands and feet of the personnel should be detected and measured. A scintillation probe that shows lower MDA for alpha and beta radiation is able to measure such contamination.

A plastic scintillation probe with ZnS(Ag) phosphor at the top of the plastic scintillator produces, at the output of PMT pulses with a distinctly different decay scintillation time of beta and alpha radiation. This enables pulse shape discrimination of beta and alpha nuclides and simultaneous measurements of both types of contamination.

The scintillation probe can well replace the proportional counter. Mechanical break down or puncture of the delicate measuring window can easily be repaired. Cost of the main components of the probe (plastic scintillators, aluminized foil, PMT), is more than two times lower than that of the detection probe with a proportional counter.

The GM detection probe shows lower MDA for alpha and beta radiation than the proportional counter. The main problem of the GM probe is that its active detecting surface makes approximately 50% of the total measuring surface. The other 50% is not active. In a dosimetric gate of the whole body where detection probes are spaced from each other at some distance, the dead area of GM probe has no greater significance comparing to the dead space between the probes, and that the GM probe can be accepted for such applications. Cost of the GM probe is more than two times lower comparing to the proportional counter probe. Mechanical construction and electronic circuits are simple, and operation of the probe stable.

MDA for gamma radiation of the scintillation probe is approximately 2 times higher than that of the proportional counter probe and the proportional counter is comparable with GM probe.

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References

1. DSP-15 dosimetric gate, www.ichtj.waw.pl/ltj/
2. Hanna hand-foot contamination monitors, www.raytest.com
3. Hasegawa T, Hashimoto T, Hashimoto M (2004) Radioactive contamination monitors. Fujielectric Rev 50;4:118–124
4. Med Nuklearmedizinetechnik Hand-Foot-Clothing Contamination Monitor, www.medical.siemens.com
5. Multi pixel photon counter, S10362-33-050C, www.hamamatsu.com
6. PN-EN 60325 Radiation protection instrumentation – alpha, beta and alpha/beta (beta energy > 60 keV) contamination meters and monitors, www.findstandards.info.StandardsPage/18700.html
7. Recommended limits on radioactive contamination on surfaces in laboratories (1995), www.arpansa.gov.au/pubs/rhs/rhs38.pdf