CALIBRATION FACTOR OF THE TCS-172 GAMMA SURVEY METER AS A FUNCTION OF GAMMA DOSE RATE IN THE LABORATORY

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ABSTRACT

A Cs-137 radioactive source was used to calibrate the TCS-172 gamma survey meter (TCS-172 GSM) at the Training Center, Nuclear Research Institute, Vietnam, with a gamma dose rate between 0.29 µSv/h and 1.90 µSv/h. All the instruments for this experiment were placed in a Pb chamber to reduce the contribution of the radiation background to the measurement values. We found the calibration factors of the TCS-172 GSM in the range of 0.73-0.84 and as a function of the gamma dose rate.

Keywords: *Calibration factor; gamma survey meter; NaI(Tl); TCS-172*

1. Introduction

Nuclear research centers and university nuclear laboratories commonly use NaI(Tl) detectors for nuclear radiation measurement. NaI (Tl) can be attached to a multi-channel gamma spectrometer to determine the content of elements [1-2] or to a portable device to determine the gamma dose rate [3-4]. For these devices to give accurate results, they need to be calibrated, and the gamma spectrometer is calibrated based on the efficiency curve using some standard radioisotope sources such as Cs-137 and Co-60 [5-6]. In contrast, the portable gamma dose rate measuring devices are calibrated based on the calibration factor and use only the Cs-137 source [7].

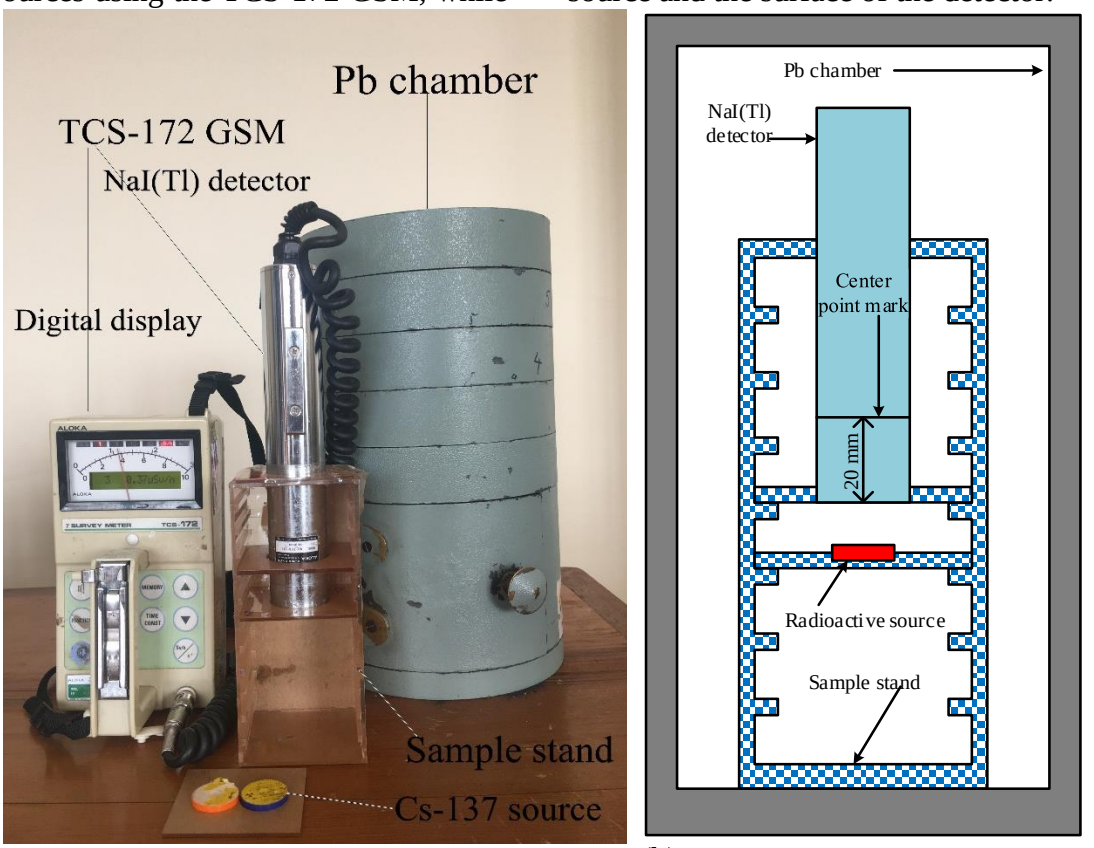
In Vietnam, portable radiation measuring devices are usually calibrated once a year at specialized and licensed centers such as the Center for radiation Protection of the Nuclear Research Institute. This center often uses Cs-137 sources with high activity and calibrates gamma dose rates in the range > 5 µSv/h [7]. However, nuclear radiation measurement laboratories often use conventional sources, such as Cs-137 and Co-60, with modest activities (dose rates). Cs-137 source typically has an activity of 0.25 µCi when manufactured, corresponding to a dose rate of around 1.8 µSv/h [8]. This value is rarely assigned a calibration factor in our device's calibration certificate. The objective of this work is to determine the calibration factor for the TCS-172 GSM device in the dose rate range of less than 1.8 µSv/h using the Cs-137 isotope source to serve the teaching work for students majoring in nuclear physics at the Training Center of the Nuclear Research Institute.

2. Materials and methods

2.1. Materials

The TCS-172 GSM has a detector with a 25.4ϕ x 25.4 mm NaI(Tl) scintillator and an energy compensation

for gamma rays [3]. Fig. 1a illustrates the components of the system to detect the gamma dose rate due to the Cs-137 sources using the TCS-172 GSM, while Fig. 1b shows the arrangement for the instruments to measure the gamma dose rate at various positions between the source and the surface of the detector.



(a) (b)

Fig. 1: *(a) The instruments used in the experiment to determine the calibration factor. (b). Experimental setup for studying calibration factor*

In this investigation, we employed two sources of Cs-137, each with an initial activity of 0.25 µCi, provided by Oak Ridge, Tennessee-based Spectrum Techniques [8]. The first source (created in January 2015) was used to calibrate the TCS-172 GSM, while the second source (produced in December 2013) was employed to validate the above-mentioned calibration factors. Some characteristics of these radiation sources is presented in Table 1.

Table 1: *Some characteristics of these radiation sources used in this study* [8]

No.	Source	A_0 [µCi]	T [year]	Manufactured	A [Bq], 20/02/2025
1	Cs-137	0.25	30.1	01/2015	7308.20
2	Cs-137	0.250	30.07	12/2013	7140.31

2.2. Theoretical calculation for the gamma dose

The gamma dose rate due to a point radioactive source generates at a point of interest [9-10] is calculated according to the following formula:

$$\dot{H} = \frac{0.576 \times A \times f \times E_\gamma \times \left(\frac{\mu_{en}}{\rho}\right)_{air}}{4\pi d^2} \quad (1)$$

where $\dot{H}$ is the gamma dose rate in µSv/h, A is the activity of the radioactive source in Bq, f is the gamma rays emission probability, E_γ is the gamma rays energy in MeV, $(\mu_{en}/\rho)_{air}$ is the mass energy absorption coefficient of the air corresponding to gamma rays with energy E_γ in cm^2/g, and d is the distance from the radioactive source to the center point mark of the detector (in experimental measurement) or the interested point (in theoretical calculation) in cm.

The values of 0.85, 0.662, and 0.0293 correspond to the gamma-ray emission probability, the gamma rays energy, and the mass energy absorption coefficient of the air for the above gamma rays [9]. Then Eq. (1) was used to compute the gamma dose rate for each distance step from the source, starting at 2 cm. According to the TCS-172 GSM instruction manual, the NaI(Tl) detector's center position is 20 mm within the front face of the scintillation probe [3].

2.3. Experimental procedure

First, the TCS-172 GSM was installed to detect the gamma dose rate of the first Cs-137 source at positions that were calculated in the previous step (II.2). Then, we calculated the calibration factor at each position, which is the ratio between the measured and computed gamma dose rates. Finally, in order to assess the values of the mentioned calibration factor, we calculated the activity of the second Cs-137 source based on measuring the gamma dose rate and the calibration factor.

In our laboratory, the unshielded radiation background for calibration factor measurements was approximately 0.2 µSv/h for TCS-172 GSM; however, utilizing a lead chamber to shield the NaI(Tl) detector of the TCS-172 GSM reduced the radiation background to 0.04 µSv/h. So, we placed the equipment for these experiments, including the radioactive sources, sample stand, and the NaI(Tl) detector into the lead chamber, as shown in Fig. 1b.

3. Results and discussion

3.1. Determination of calibration factor of TCS-172 GSM using the first Cs-137 source

Table 2 displays experimental results for the first source's gamma dose rate with a distance in the range of 2.0 cm to 4.8 cm from the radiation source to the detector's center point mark. The statistical uncertainties were estimated, and one standard deviation (1σ) errors were applied to the data, and these errors were only less than 5%.

Table 2: *Measured results of gamma dose rate with the first Cs-137 source*

No. of mea.	Bgr.	Gamma dose rate [µSv/h]				
		2.0 [cm]	3.0 [cm]	3.4 [cm]	4.4 [cm]	4.8 [cm]
1	0.03	1.97	0.83	0.66	0.39	0.32
2	0.04	1.89	0.82	0.64	0.39	0.33

No. of mea.	Bgr.	Gamma dose rate [µSv/h]				
		2.0 [cm]	3.0 [cm]	3.4 [cm]	4.4 [cm]	4.8 [cm]
3	0.04	1.94	0.84	0.62	0.38	0.32
Dose rate_ave.	0.037 ± 0.003	1.933 ± 0.023	0.830 ± 0.006	0.640 ± 0.012	0.387 ± 0.003	0.323 ± 0.003
Net dose rate_ave.		1.90 ± 0.02	0.79 ± 0.01	0.60 ± 0.01	0.35 ± 0.01	0.29 ± 0.01

Table 3 shows both theoretical and experimental data for the first source's gamma dose rate. Based on this data table, the calibration factor for each position was computed, which was the ratio between the gamma dose rates of experimental measurement and theoretical calculation values. Fig.2 displays the calibration factor versus the gamma dose rate of the first Cs-137 source for the TCS-172 GSM. As seen in Fig. 2, the calibration factor of the TCS-172 GSM seems to be decreasing exponentially with the gamma dose rate.

Table 3: *Calibration factor obtained from calculated and measured results of the gamma dose rate*

No.	d [cm]	Gamma dose rate [µSv/h]		Calibration factor
		Theoretical calculation	Experimental result	
1	2.0	1.38	1.90	0.73
2	3.0	0.61	0.79	0.77
3	3.4	0.48	0.60	0.79
4	4.4	0.29	0.35	0.82
5	4.8	0.24	0.29	0.84

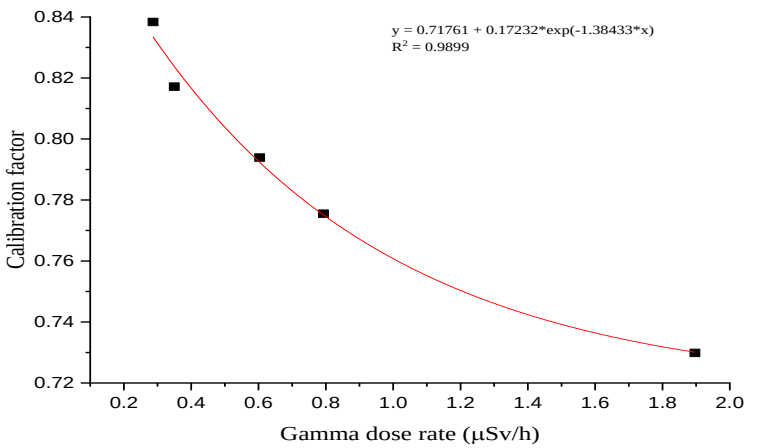


Fig. 2: *Calibration factor as a function of gamma dose rate for a TCS-172 GSM using the first Cs-137 source*

3.2. Activity determination of the second Cs-137 source

In order to reduce error in calculating the activity of the second Cs-137 source, we have chosen the range of the gamma dose rate from 1.82 µSv/h to 0.57 µSv/h and corresponded to the distance from 2.0 cm to 3.4 cm. Table 4 shows the experimental results for the second source's gamma dose rate at distances ranging from 2.0 cm to 3.4 cm between the radiation source and the detector's center point mark. We also calculated statistical uncertainty and added one standard deviation (1σ) error to the data, resulting in an error of fewer than 2%.

Table 4: *Measured results of gamma dose rate with the second Cs-137 source*

No. of mea.	Bgr.	Gamma dose rate [µSv/h]		
		2.0 [cm]	3.0 [cm]	3.4 [cm]
1	0.03	1.85	0.83	0.61
2	0.04	1.89	0.84	0.60
3	0.04	1.83	0.84	0.61
Dose rate_ave.	0.037 ± 0.003	1.857 ± 0.018	0.837 ± 0.003	0.607 ± 0.003
Net dose rate_ave.		1.82 ± 0.02	0.80 ± 0.01	0.57 ± 0.01

The correction factors for the gamma dose rates of the second Cs-137 source were calculated using the calibration factor function in Fig.2, and the activity of this radiation source was then computed using the corrected gamma dose rates. The results of these calculations are shown in Table 5.

Table 5: *Calculated activity based on corrected result of gamma dose rate for second Cs-137 source*

No.	d [cm]	Exp. Result of gamma dose rate [µSv/h]	Calibration factor	Cor. result of gamma dose rate [µSv/h]	Activity [Bq]
1	2.0	1.82 ± 0.02	0.73148	1.33129 ± 0.01463	7,038.27 ± 77.35
2	3.0	0.80 ± 0.01	0.77454	0.61963 ± 0.00775	7,370.70 ± 92.19
3	3.4	0.57 ± 0.01	0.79589	0.45366 ± 0.00796	6,931.35 ± 121.62

Table 5 displays the activity values of the second Cs-137 source, ranging from 6,931.35 to 7,370.70 Bq, with an average of (7,128.75 ± 53.27) Bq. This average activity is consistent with the figure of 7,140.31 Bq computed and

presented in Table 1.

4. Conclusion

The TCS-172 SGM calibration factor for gamma dose rates less than 1.8 µSv/h using the Cs-137 source in this study is reliable and significant when compared to the average calibration factor of 1.06 for the dose rate range from 6.9 µSv/h to 30.3 µSv/h provided by the reference document [7]. The findings of this study are still important to the training of nuclear physics students at universities, as well as young researchers at the Training Center of the Nuclear Research Institute.

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HỆ SỐ HIỆU CHUẨN CỦA MÁY ĐO GAMMA TCS-172 NHƯ LÀ MỘT HÀM CỦA SUẤT LIỀU GAMMA TRONG PHÒNG THÍ NGHIỆM

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TÓM TẮT

Một nguồn phóng xạ Cs-137 được sử dụng để hiệu chuẩn máy đo gamma TCS-172 (TCS-172 GSM) tại Trung tâm Đào tạo, Viện Nghiên cứu hạt nhân, Việt Nam với suất liều gamma nằm trong khoảng 0,29 µSv/h và 1,90 µSv/h. Thiết bị đo gamma trong thí nghiệm này được đặt bên trong buồng chì để giảm sự đóng góp của bức xạ phông đến các giá trị đo. Kết quả của chúng tôi cho thấy, các hệ số hiệu chuẩn của TCS-172 GSM nằm trong dải từ 0,73 đến 0,84 và là một hàm của suất liều gamma.

***Từ khóa**: Hệ số hiệu chuẩn; máy đo gamma; NaI(Tl); TCS-172*