

# Calibration of Miniaturized Tissue Equivalent Proportional Counter with Monte Carlo Simulations with Function Fitting

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## 1. Introduction

A tissue equivalent proportional counter (TEPC) has good performance at microdosimetry in the mixed radiation fields [1]. A miniaturized TEPC (mini-TEPC), whose the size is smaller 10 times than the conventional TEPC, is helpful for the intense radiation fields like clinical beams because it prevents the pile-up of signals [2]. Due to its small cavity size, indirectly ionizing sources like photon and neutron are required to calibrate the mini-TEPC. These sources have ‘edge,’ which means the maximum lineal energy deposited in the TEPC. This study investigated the proper calibration method using <sup>137</sup>Cs photon source and <sup>252</sup>Cf neutron source with Monte Carlo simulation codes (Geant4 and MCNP). By the comparison with the calculated analytical edges of the photon and the neutron, the methodology was discussed.

## 2. Materials and Methods

### 2.1 Mini-TEPC

The mini-TEPC developed at Legnaro National Laboratories (LNL, Italy) [2] has a cylindrical gas cavity filled with tissue equivalent (TE) gas with a size of ~ a few millimeters. The A-150 TE plastic is the cathode and wall of the detector with a thickness of 0.35 mm, and it’s insulated with a Rexolite barrier. The cross-section of the detector is shown in Fig. 1.

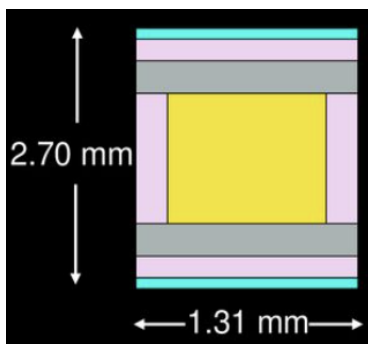


Fig. 1. The cross-section of the mini-TEPC. The yellow rectangular is the TE gas volume, the gray wall is the A-150 plastic, and others are insulated wall materials.

### 2.2 Monte Carlo Simulation

In this study, the Monte Carlo simulations were conducted with Geant4 toolkit version 10.02.p03 and

MCNP 6.2. Two isotopes, <sup>137</sup>Cs and <sup>252</sup>Cf, were used as the photon and the neutron sources, respectively, and their histories were  $1 \times 10^{10}$  for <sup>137</sup>Cs and  $1 \times 10^9$  for <sup>252</sup>Cf. We designed a simple detector of a cylindrical gas cavity of 1 mm diameter and height. The wall is A-150 TE plastic of 0.1 mm thickness. To lower the computation time and statistical uncertainty, four identical detectors were deployed around a point source, as shown in Fig. 2.

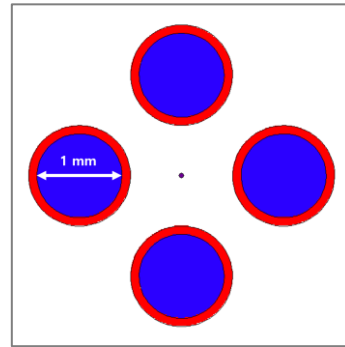


Fig. 2. Four identical detectors surrounding the point source in the middle point. The blue circle is the propane-based TE gas and the red ring is the A-150 plastic.

### 2.3 Calibration

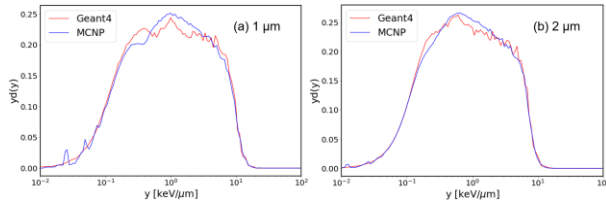
The secondary particles generated by the photon or neutron have a broad energy spectrum, but there’s specific lineal energy deposited in the mini-TEPC, called edge. By fitting to the proper Fermi-like function, the edge can be obtained [3].

$$hd(h) = \frac{A}{1 + e^{B(h-C)}} \quad (1)$$

For the dose distribution spectrum in terms of the pulse height  $h$ , the edge region, which is a steeply dropping region, is fitted to the function in equation (1). Three markers,  $h_{flex}$  (inflection point),  $h_{\delta\delta}$  (maximum of the second derivative), and  $h_{IC}$  (intercept of the tangent through the inflection point with the  $h$ -axis), are then calculated and compared to the analytical edge. The analytical electron and proton edges were calculated with the reference table of ranges of electrons and protons in the NIST dataset [4, 5].

## 3. Results and Discussion

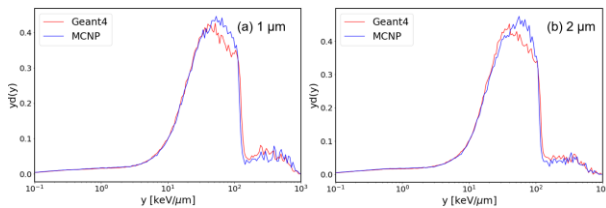
The dose distribution spectra  $yd(y)$  of 1 and 2  $\mu\text{m}$  tissue site sizes for the  $^{137}\text{Cs}$  simulation are shown in **Fig. 3**. The position of the peak and the steeply dropping region at  $\sim 10$  keV/ $\mu\text{m}$  are in good agreement, which means the electron edge will also be in good agreement.



**Fig. 3.** Microdosimetric spectra  $yd(y)$  of  $^{137}\text{Cs}$  simulations.

**Table 1** shows the three markers calculated at the fitted Fermi-like function. Among these markers,  $y_{\delta\delta}$  was closest to the analytical electron edge for 1 and 2  $\mu\text{m}$  simulations.

The dose distribution spectra for  $^{252}\text{Cf}$  simulations are also shown in **Fig. 4**. The maximum value is higher in the MCNP result, but the proton edge region is still in good agreement at  $\sim 100$  keV/ $\mu\text{m}$ .



**Fig. 4.** Microdosimetric spectra  $yd(y)$  of  $^{252}\text{Cf}$  simulations.

The three markers of proton edge are smaller at the MCNP than the Geant4 because the higher peak at the MCNP made the three markers decrease, which are influenced by the gradient of the fitted function. The analytical proton edge increased when the site size increased, while the calculated markers decreased. The

neutrons generated heavier charged particles like alpha particles, which made some peaks at the tail of the spectrum. The markers vary according to the shape of the spectrum.

#### 4. Conclusions

For the development of a mini-TEPC that can be applied to the various radiation measurements, the precise calibration of the TEPC is required. With the Geant4 and the MCNP simulations, we investigated the methodology using the Fermi-like function. In the case of the photon source ( $^{137}\text{Cs}$ ), the second marker,  $y_{\delta\delta}$ , was closest to the analytical electron edge for both Geant4 and MCNP. However, the markers of the proton edge showed disagreement. More studies for calculating the proton edge using the neutron source will be carried out.

#### REFERENCES

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- [4] NIST: <http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html>
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**Table 1.** The three markers of the electron edge calculated with the fitted Fermi-like function

Site size	1 $\mu\text{m}$			2 $\mu\text{m}$		
	Marker	$y_{flex}$ (keV/ $\mu\text{m}$ )	$y_{\delta\delta}$ (keV/ $\mu\text{m}$ )	$y_{TC}$ (keV/ $\mu\text{m}$ )	$y_{flex}$ (keV/ $\mu\text{m}$ )	$y_{\delta\delta}$ (keV/ $\mu\text{m}$ )
Geant4	9.33	11.63	12.83	6.8	8.64	9.6
MCNP	8.44	11.53	13.13	6.27	8.58	9.78
Analytical		11.15			8.36	

**Table 2.** The three markers of the proton edge calculated with the fitted Fermi-like function

Site size	1 $\mu\text{m}$			2 $\mu\text{m}$		
	Marker	$y_{flex}$ (keV/ $\mu\text{m}$ )	$y_{\delta\delta}$ (keV/ $\mu\text{m}$ )	$y_{TC}$ (keV/ $\mu\text{m}$ )	$y_{flex}$ (keV/ $\mu\text{m}$ )	$y_{\delta\delta}$ (keV/ $\mu\text{m}$ )
Geant4	127.52	142.6	150.43	117.2	132.17	139.93
MCNP	119.76	129.91	135.17	110.92	121.7	127.29
Analytical		141			146	