Electron and proton edge calibration for a propane-filled TEPC

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Abstract: The tissue equivalent proportional counter (TEPC) has been demonstrated as a valuable tool for dosimetry in mixed radiation environments such as in space, nuclear power plants and alternative radiotherapy beams. In the absence of an internal alpha calibration source, the calibration of TEPCs in terms of lineal energy (keV/μm) is conducted using external photon or neutron sources. Specific points (also called as markers) with known values of lineal energy ($y_{Flex}, y_{\delta\delta}$ *and* y_{tC}) along the electron and proton edges exhibited by these sources are used as calibration points. In this work, we aim to establish formalisms for calibration of spherical TEPCs filled with pure propane gas using markers for Cs-137 gamma and Cf-252 neutron fields through Monte Carlo simulations. The results showed that the relationship of the site diameter with the electron edge markers can be expressed through a power function while for proton edge markers, a simple linear equation was obtained. In, addition, Cs-137 calibration equations for $y_{\delta\delta}$ *and* y_{tC} were proven to also be useful to other photon energies. However, the same cannot be said for the proton edge markers as their energy dependence was not covered in the present study.

1. Introduction

A tissue equivalent proportional counter (TEPC) is typically equipped with an internal alpha source for calibration. For instances wherein an internal calibration source is not available or is difficult to be incorporated in the detector design, self-calibration is performed using external photon or neutron sources. Previous works suggested methods on calibrating cylindrical mini and spherical TEPCs filled with propane-based TE gas (54% C_3H_8, 40.5% CO_2, 5.5% N_2) using identifiable points in the *electron* and *proton edge* regions [1, 2]. These regions are characterized by a sudden drop in the microdosimetric spectra of photons and neutrons attributed to the energy released by secondary electrons and recoil protons that traversed the longest chord of the cavity [3].

TEPCs intended for monitoring in space are normally filled with pure propane gas (C_3H_8) because it offers longer stability and greater gas gain [4]. The difference in the mass collisional stopping powers of pure propane and propane-based TE gas indicates different responses for the same simulated site size. Thus, numerical simulations were performed in this work in an effort to establish a calibration method appropriate for propane-filled TEPCs.

2. Methods and Results

2.1 Monte Carlo (MC) Simulation

Monte Carlo simulations of the 60 mm diameter spherical TEPC developed by the Korea Astronomy and Space Science Institute (KASI) were carried out using the Geant4 simulation toolkit version 10.3 to acquire the microdosimetric spectra ($yd(y)$) for Cs-137 gamma and Cf-252 neutron sources. The sensitive volume was filled with pure propane gas at different pressures to observe distributions expected for site sizes 0.3, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 μm. The corresponding gas pressures and mean chord lengths for each site size are presented in Table I. The source was assumed to be a 90 mm × 90 mm parallel plane emitting 662 keV photons for the Cs-137 case. Meanwhile, the energy distributions of the mixed neutron and gamma field from spontaneous fission of Cf-252 were sampled from the Lawrence Livermore National Laboratory (LLNL) fission model [5].

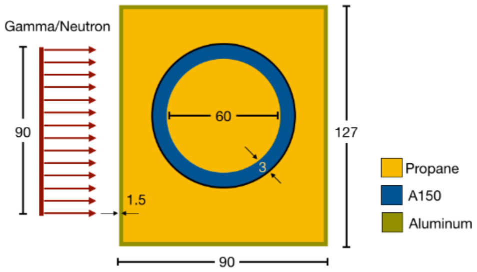

Fig. 1. Schematic diagram of the TEPC simulation with the source modelled as a 90 mm × 90 mm parallel plane emitting neutrons and gamma rays.

Table I: Corresponding mean chord length and gas pressure for each simulated site size.

Site Size (μm)	Mean Chord Length (keV/μm)	Pressure (Torr)
0.3	0.2	2.07
0.5	0.33	3.45
1	0.67	6.91
1.5	1	10.4
2	1.33	13.9

2.5	1.67	17.3
3	2	20.7

The energy deposited per event in the gas cavity was recorded and subsequently transformed to the lineal energy by dividing it with the mean chord length. An in-house MATLAB code was created to construct the microdosimetric spectra (also called lineal energy distribution) following the formalisms recommended in ICRU 36 [5]. Fig. 2(a) and (b) depict the effect of increasing site size (i.e., increase in gas pressure) to the lineal energy distributions for Cs-137 and Cf-252, respectively. For both cases, the spectrum shifted to lower lineal energy values as the site size was increased.

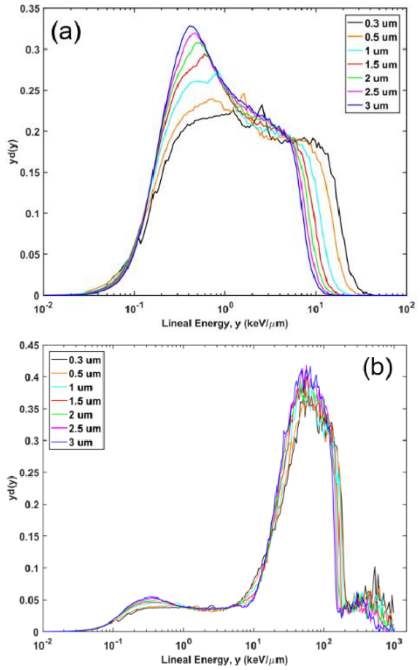

Fig. 2. (a) Cs-137 and (b) Cf-252 microdosimetric spectra obtained at different site sizes in pure propane

2.2 Electron/Proton Edge Calibration Method

Using the formalism described in Conte *et al*'s work [1], a fermi-like function was fitted to the electron edge and proton edge regions and the inflection point (y_{Flex}), second derivative maximum ($y_{\delta\delta}$) and the intercept of the tangent through the inflection point (y_{tC}) were obtained as shown in Fig. 3. This procedure was repeated for all site sizes for both the gamma and neutron cases.

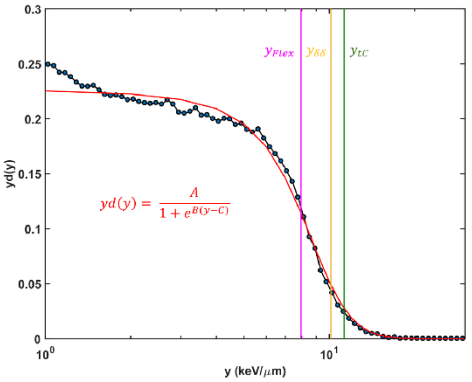

Fig. 3. Fitting of a fermi-like function to the yd(y) spectra and identification of the electron and proton edge markers ($y_{Flex}, y_{\delta\delta}, y_{tC}$) to be used in calibration.

The mathematical relationship between the site size (*D*) and each marker was obtained wherein γ and n denotes markers for Cs-137 and Cf-252, respectively. A separate simulation for a 0.7 μm site size was also performed for validation. The markers obtained from fermi-fitting and those calculated from the analytical expressions below were compared. The largest deviations on the predicted marker values for Cs-137 and Cf-252 were 0.3% and 0.6%, respectively.

$$\begin{aligned} y_{Flex-\gamma} &= 11.1D^{-0.42} \\ y_{\delta\delta-\gamma} &= 13.6D^{-0.42} \\ y_{tC-\gamma} &= 14.8D^{-0.42} \end{aligned} \tag{1}$$

$$\begin{aligned} y_{Flex-n} &= -17.9D + 188.6 \\ y_{\delta\delta-n} &= -20.4D + 210.8 \\ y_{tC-n} &= -21.6D + 222.4 \end{aligned} \tag{2}$$

2.3 Validity for other photon energies

It has been reported that the position of the electron edge is relatively invariant to photon energy [6]. Thus, the lineal energy distributions for a 2 μm site size at various photon energies (E = 0.177, 0.338, 0.83, 1.32 and 2 MeV) were also acquired as illustrated in Fig. 4. The applicability of the analytical equations (equation 1) obtained for 662 keV photons in predicting the electron edge markers for a different photon energy was also assessed. Apart from y_{Flex}, the deviation in the markers considering all energies were within 3.5%.

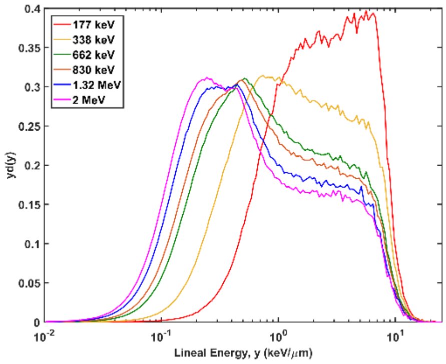

Fig. 4. Comparison of the microdosimetric spectra for photons of varying energy

3. Conclusions

Relationships between the simulated site diameter (i.e., gas pressure) in pure propane with electron and proton edge markers were established. These specific points in the microdosimetric spectra of various gamma and Cf-252 neutron sources can serve as calibration points for spherical TEPCs filled with pure propane gas. Based on the simulation results, the $y_{\delta\delta}$ and y_{tC} were shown to be less sensitive to photon energy. However, the energy dependence of the proton edge markers is yet to be confirmed. Experiments will also be carried out to validate these results.

4. Acknowledgements

This work was supported by the National Research Foundation (NRF) grant funded by the Korean government (No. NRF-2017M1A3A4A01077220).

REFERENCES

[1] V. Conte, D. Moro, B. Grosswendt and P. Colautti, Lineal energy calibration of mini tissue-equivalent gas-proportional counters (TEPC), AIP Conference Proceedings, Vol.1530, p.171-8, 2013.
[2] D. Moro, S. Chiriotti, V. Conte, P. Colautti and B. Grosswendt, Lineal energy calibration of a spherical TEPC, Radiation Protection Dosimetry, Vol.166, p.233-7, 2015.
[3] J. S. P. Crossman and D. E. Watt, Inherent Calibration of Microdosemeters for Dose Distribution in Lineal Energy, Radiation Protection Dosimetry, Vol.55, p. 295-8, 1994.
[4] S. Chiriotti, D. Moro, P. Colautti, V. Conte and B. Grosswendt, Equivalence of pure propane and propane TE gases for microdosimetric measurements, Radiation Protection Dosimetry, Vol.166, p. 242-6, 2015.
[5] J. Verbeke, C. Hagmann and D. Wright, Simulation of neutron and gamma ray emission from fission and photofission (UCRL-AR-228518-REV-1), Lawrence Livermore National Laboratory, 2016.
[5] International Commission on Radiation Units and Measurements, Microdosimetry, 1983, Bathesda, MD.
[6] D. Moro, E. Seravalli and P. Colautti, Statistical and Overall Uncertainties in BNCT Microdosimetric Measurements (LNL-REP 199/2003)