Response of a Novel Avalanche-Confinement TEPC to Photons and Fast Neutrons

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INTRODUCTION

The tissue equivalent proportional counter (TEPC) is the most accurate device for measuring the microdosimetric properties of a particle beam, showing to properly assess the relative biological effectiveness by linking the physical parameters of the radiation with the corresponding biological response. Nevertheless no detailed information on the track structure of the impinging particles can be obtained, since the lower operation limit of the common TEPCs is about 0.3 μm. On the other hand, the pattern of particle interactions at the nanometer level, which demonstrated to have a strong correlation with radiation-induced damages to the DNA, is directly measured by only three different nanodosimeters worldwide[1], practical instruments are not yet available. The gap between microdosimetry and track-nanodosimetry can be filled partially by extending the TEPC response down to the nanometric region.

A feasibility study of a novel TEPC designed to simulate biological sites in the nanometric domain was performed in the framework of the MITRA Project (Microdosimetria e struttura di TRAccia) of the Italian National Institute for Nuclear Physics (INFN), whose main purpose is the measurement of the ionizations and energy fluctuations due to light ions of therapeutic interest in sites ranging from nanometric to micrometric size.

After a brief description of the microdosimeter, the present report aims at reporting the experimental results obtained by irradiating the device with a photon field generated by a Cs-137 source and with a fast neutron beam. The microdosimetric spectra demonstrated the capability of this TEPC of measuring in the range 0.3 μm - 25 nm.

THE MICRODOSIMETER

An innovative TEPC based on a three-electrodes structure and capable of performing microdosimetric measurements from 0.3 μm down to 25 nm in simulated site size, was designed basing on a prototype[2]. The peculiarities of the new design are mainly a thinner wall chamber, which allows the microdosimeter to measure low-energy (and high-LET) hadron beams. Moreover, a removable internal alpha source and a very compact solid state detector were inserted inside the sensitive zone for energy calibration purposes. Figure 1 shows the cross sectional view of the new avalanche-confinement TEPC.

A customized and transportable vacuum and gas flow system was developed in order to guarantee vacuum conditions and ensure a continuous replacement of tissue equivalent gas inside the chamber. In such a way, the high purity required for stable gas gain during the irradiation is preserved and the ageing and outgassing effects are minimized. Dimethyl ether (DME: (CH₃)₂O) is the selected filling gas for this avalanche-confinement TEPC: it can be considered as a tissue-equivalent gas, apart from the lack of nitrogen[3].

The edge technique usually performed with common TEPCs is not adequate for the lineal energy calibration of this avalanche-confinement TEPC, because its particular design (presence of the third electrode) and its operating conditions (very low gas pressures) do not guarantee the correctness of this kind of procedure. For this reason, an internal Cm-244 alpha source was used to perform the lineal energy calibration. The effective absorbed energy in the gas depends on the simulated site size, i.e. on the gas pressure, but is not affected by the applied voltages to the electrodes. On the contrary, the amplitude of the signal collected by the TEPC strongly depends on both the gas pressure and ΔV_e-h. For this reason, a correlation between the energy of the alpha particle which is absorbed by the gas and the corresponding TEPC signal output was characterized as a function of the gas pressure and of the potential difference between the anode wire and the helix. More details about the whole measurement system and the first operation tests can be found in references [4] and [5].

RESPONSE TO A Cs-137 PHOTON FIELD

The response of this novel avalanche-confinement TEPC to a photon field generated by a Cs-137 isotopic source having an activity of 1.11·10⁹ Bq was assessed at the Microdosimetry Laboratory of the INFN-Laboratori Nazionali di Legnaro (LNL-INFN). Several configurations were tested by varying both the simulated site size (that is the gas pressure) and the voltage difference ΔV_e-h between the helix and the anode wire, i.e. inside the multiplication region of the sensitive volume.

Figure 2 (on the left) shows the results obtained for a simulated site size of 100 nm at two different ΔV_e-h, i.e. 400 V and 430 V, respectively. The spectrum at 430 V is shifted...
towards higher values with respect to the one at 400 V, since in the former condition the gain of the counter is higher. Nevertheless, if the pulse height dose distributions hd(h) are converted into lineal energy spectra yd(y) by applying the energy calibration as shown in Figure 2 (on the right), the electron edge of the two spectra at high lineal energies agrees very well. This is the demonstration of the correct functioning of the device. In fact, the lineal energy distributions depend on the cavity size and on the energy and type of particle, but must not depend on the operating parameters of the counter, that is the bias voltage of the electrodes. The obtained distributions confirm that the tested operating parameters of the device, i.e. the bias voltages of the electrodes which regulate the multiplication process, do not affect the microdosimetric information measured by the detector, which depends on the cavity size and on the radiation field. To give an impression of the complete results, Figure 3 shows all the calibrated gamma spectra measured at 300, 100, 50, 35, 30, 25 nm (right).

Fig. 2: Dose distributions hd(h) and yd(y) obtained by irradiating the microdosimeter with a Cs-137 gamma source for a simulated site size of 100 nm at ΔV_{+h} equal to 400 V and 430 V

Fig. 3: Microdosimetric spectra obtained by irradiating the device with a Cs-137 photon field at 300, 100, 50, 35 nm (left) and 35, 30 and 25 nm (right).

The graphs show the same trend as a function of the site size: the spectra shift towards higher y values as the TEPC cavity size reduces. This is due to the change in the energy of electrons that are exact stoppers. As the site size reduces, the energy of exact stoppers reduces and their stopping power increases.

**RESULTS WITH HIGH ENERGY NEUTRONS**

Irradiations with a high-energy neutron field produced at the CN Van de Graaff accelerator of the INFN-Laboratori Nazionali di Legnaro (LNL-INFN) were performed. Fast neutrons up to 20 MeV were generated through the ^7Li(d,n)^7Be reaction with 5.5 MeV deuterons striking a thick Lithium target. This experimental characterization was carried out for simulated site sizes in the range 300 nm - 25 nm at different bias voltages. Figure 4 shows neutron spectra measured at 300, 100, 50, 35, 30 and 25 nm. Because of different values in the minimum detectable lineal energy, the spectra were normalized in order to obtain equal integrals for lineal energies above about 23 keV μm\(^{-1}\) (threshold at 25 nm). The main proton peak at 300, 100 and 50 nm is slightly shifted at higher lineal energies with respect to the other simulated sites. The distributions at 35, 30 and 25 nm show a very similar shape, but different acquisition thresholds due to different values of the respective gain. At 30 nm the main proton peak is still visible, even if located just above the threshold, while at 25 nm the limit condition is reached and only a small portion of the proton peak and of the contribution of light ions are present.

The reason of the discrepancy in the proton edge of the distributions measured at 300, 100 and 50 nm with respect to those derived at lower simulated sites is still under investigation.

Fig. 4: Comparison between all measured neutron distributions at different simulated site sizes.

**CONCLUSIONS**

This avalanche-confinement TEPC showed to be capable of measuring in the range 0.3 μm - 25 nm when irradiated with photons and high energy neutrons. A future work will be devoted to irradiations with monoenergetic neutron fields in order to compare directly the experimental results with Monte Carlo simulations.