CLUSTERS OF IONIZATION AT NANOMETRE TARGETS IN PROPANE- EXPERIMENT WITH JET COUNTER.

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Abstract

Further evidences on the reliability of the device called Jet Counter for studying the formation of ionisation clusters at nanometre level are presented. The new experimental data on distribution of ionisation cluster size originating at 2- 10 nm target size in propane irradiated by 4.6 MeV alpha particles are described. The simulated targets were produced in a device called the Jet-Counter, JC. It consists of a pulse-operated valve which injects an expanding jet of propane into an interaction chamber where a sensitive volume in form of a cylinder is created. The sensitive volume was irradiated by 4.6MeV alpha particles. The resulting distribution of ion clusters ranging from 2 to 10 nm at unit density gas have been measured. The method for determining the efficiency of single propane ions registration by an ion detector is described. The method of deconvolution of the measured to true cluster size distributions is given. Finally the measured cluster size distributions are compared with modelled ones based on Monte Carlo calculations. The results for propane together with previous for nitrogen place the Jet Counter as the efficient tool for an investigation of radiation quality at nanometre level.

INTRODUCTION

There are strong evidences that the initiation of radiation damage of different nature and significance to mammalian cells start at DNA molecule. More recently, clustered damage to DNA seems to have of special importance (1). These clustered damages may be initiated by corresponding ionisation clusters along a trajectory of a primary ionisation particle. Therefore the theoretical and experimental works on ionisation cluster formation at nanometer scale are a way to better understanding of the relevant complex processes in mammalian cells.

Similarly to the microdosimetry technique at micrometer scale (TEPC)(2) it has been assumed that the first approach for studying ionization processes at biological nanometer structures can be modeled by a gas cavity with a corresponding nanometre size.

Experimental microdosimetry at nanometer scale has been accomplished with a set up called JET COUNTER (3,4). First experiments has been reported at previous symposia in which ionisation cluster distribution at nanometer levels had been carried out for nitrogen cavity size of up to 13 nm irradiated with for alpha particles (5,6,7). The experiment for propane nanometre size cavities together with the relevant Monte Carlo modeling are discussed in this paper.

MATERIAL AND METHODS.

Modeling of nanometre size.

A gas cavity which simulates a nanometric volume (in unit density scale) is created by method explained in Fig 1A. A simulated nanometre size, SNS, is obtained by pulse expanding of propane(jet) to a volume of interaction chamber, IC. The IC volume, has cylindrical form 10 mm diameter and by 10 mm height, with 1mg/cm2 mylar foil walls. The propane jet is created due to pulse operated valve, PZ ,which injects propane from a volume, R, over a valve, trough a nozzle with a 1 mm diameter orifice to IC below a nozzle. At lower part of the IC, a cavity between grid S and the edge of IC is a simulated nanometre size, SNS, site ,i.e. a cavity from which ions are collected with known efficiency. The SNS cavity is schematically shown in Fig 1B as an enlargement. It forms a cylinder with height equals to its diameter, shown in Fig.1C. The timing chart of nitrogen flow through the SNS, seen in Fig.2 (bottom), has been established based on transmission of monoenergetic electrons through a layer of propane, across the diameter of SNS cavity. The minimum at a transmission curve means maximum density of propane. The maximum instant density of propane lasts around 200 us and for this time window the SNS site is defined. The instant density within interaction chamber is controlled by propane pressure inside the reservoir R. The position of an electron gun, EG, and an electron detector CH1, with respect to alpha source and Si detector is shown in Fig. 1D.

Method for measuring of ion cluster size spectra.

The collimated alpha particles, 4.6 MeV, from a source (gold plated AMM2 type Amersham) intersect a SNS chamber (alongside of its diameter) at half of its height and are registered by a Si detector. The ions created, by single alpha particle along its path (as well as by delta electrons) within the SNS, are removed by an electric field of a grid, G, then guided through G1 to DM205IG detector. The pulses from this detector are amplified by fast preamplifier VT 120 and enter the 10 ns resolution multiscaler, MCS, type 914T ORTEC. The associated electronic set up as well as the timing chart of the experiment for registering the signal clusters is shown in Fig.1A.The channel on the MCS is advanced after each pulse from Si detector. In this way a signal cluster spectrum, for a given thickness of SNS is recorded. From the recorded data, the signal cluster distribution as a function of cluster size is derived. One of the important feature of this method is ability to measure the “zero size“ event rate. The measured spectra are deconvoluted to the true number of ion spectra .

Efficiency of the ion detector for propane ions

The efficiency of the ion detector is the basic parameter which influences to the shape signal spectra and must be known. Therefore a set up for studying the efficiency of the used discrete channel electron multiplier type DM205IG was assembled and presented in Fig. 3. The special ion source have been constructed with controlled yield, seen in Fig.3 as an enlargement, for this purpose. The efficiency of the DM205IG detector was studied as a function of high voltage for different source yields, before being installed in nanometric experiment. The results are shown in Fig. 4. The absolute efficiency of single propane ions depends strongly on accelerating HV potential as seen in Figure5. The special attention has been given to reproducibilty of the efficiency measurements. The reproducibility of the results were around 1% for source yield of 10^5 ions/s.

RESULTS AND DISCUSSIONS

The actual size of SNS is derived from following equation:

$$(l\rho) = [M_1 (T) / \eta] (\lambda\rho)$$

where

M_1 (T) is the first moment of a measured cluster distribution for a given efficiency of propane ion detection η, (λρ) is the mean free path length with respect to ionisation of apha particle.

(Iρ) is diameter of SNS in

The signal cluster spectra for the cylinders with the following dimensions (diameter by height): 1,1 x1,1 nm , 2,5 x 2,5 nm and 3, 7x 3,7nm irradiated by narrow beam of 4.6 MeV alpha particles entering to the sensitive cavity through 1 mg/cm2 mylar foil (which degrades energy to 3.8 MeV), were measured. The ionisation cluster size was defined here as the number of ionizations produced by charged particle across its full track within the SNS. The cluster probability distribution was compared with that obtained by Monte Carlo calculation by Grosswendt(8) . Poisson distribution calculated from the mean cluster ionisation are included. The experimental and theoretical results are presented in Fig. 6. It must be added that no normalization procedure was applied to experimental results. It can be seen that there are some small departure from MC modeling for the higher order of cluster sizes which may be the results of higher contribution of delta electrons. This also can be seen in much larger deviation from the Poisson distribution. This departure is higher for higher dimensions of SNS. Generally, experiments with propane have given the same physical pattern as for nitrogen with some indication of larger influence on stability of the ion detector (sparks, gain change).

Based on this distribution the following parameters which directly describe radiation quality of radiation, can be derived, namely:

First moment of frequency distribution i.e. the mean number of ions (ionizations) in a cluster for a given geometry of irradiation as well as for a given simulated nanometre size

$$M_1(\nu,T) = \sum_{k}^{\infty} \nu P(\nu,T)$$

Cumulative frequency of obtaining cluster size $F_k(\geq\nu) = \sum_{k}^{\infty} P(\nu,T)$ for $\nu = 1,2,3,4$

It has been shown (9) that ratio of the first moment to cumulative distribution for 2 nm site size correlate positively with the ratio of single strand to double strand brakes as reported by Kampf (10).

CONCLUSIONS

It has been confirmed that the JET COUNTER is an unique setup with ability to simulate the cylindric.al sensitive volumes at nanometre levels using propane or nitrogen. The experimental data given by JET COUNTER are single track related and the frequency distribution of cluster size for a given charged particle versus ion cluster size derived experimentally for 2 nm site size can be assumed as new descriptor of radiation quality for radiological protection.

The parameters characterizing the cluster distribution for nanometre sensitive volume like: First moment of distribution, cumulative distribution as well the ratio of first moment to cumulative distribution for selected cluster size are the candidate for physical description for radiation protection and radiobiology.

The presented results for propane together with previous for nitrogen place the Jet Counter as the efficient tool for investigation of radiation quality at nanometre level.

ACKNOWLEDGEMENTS

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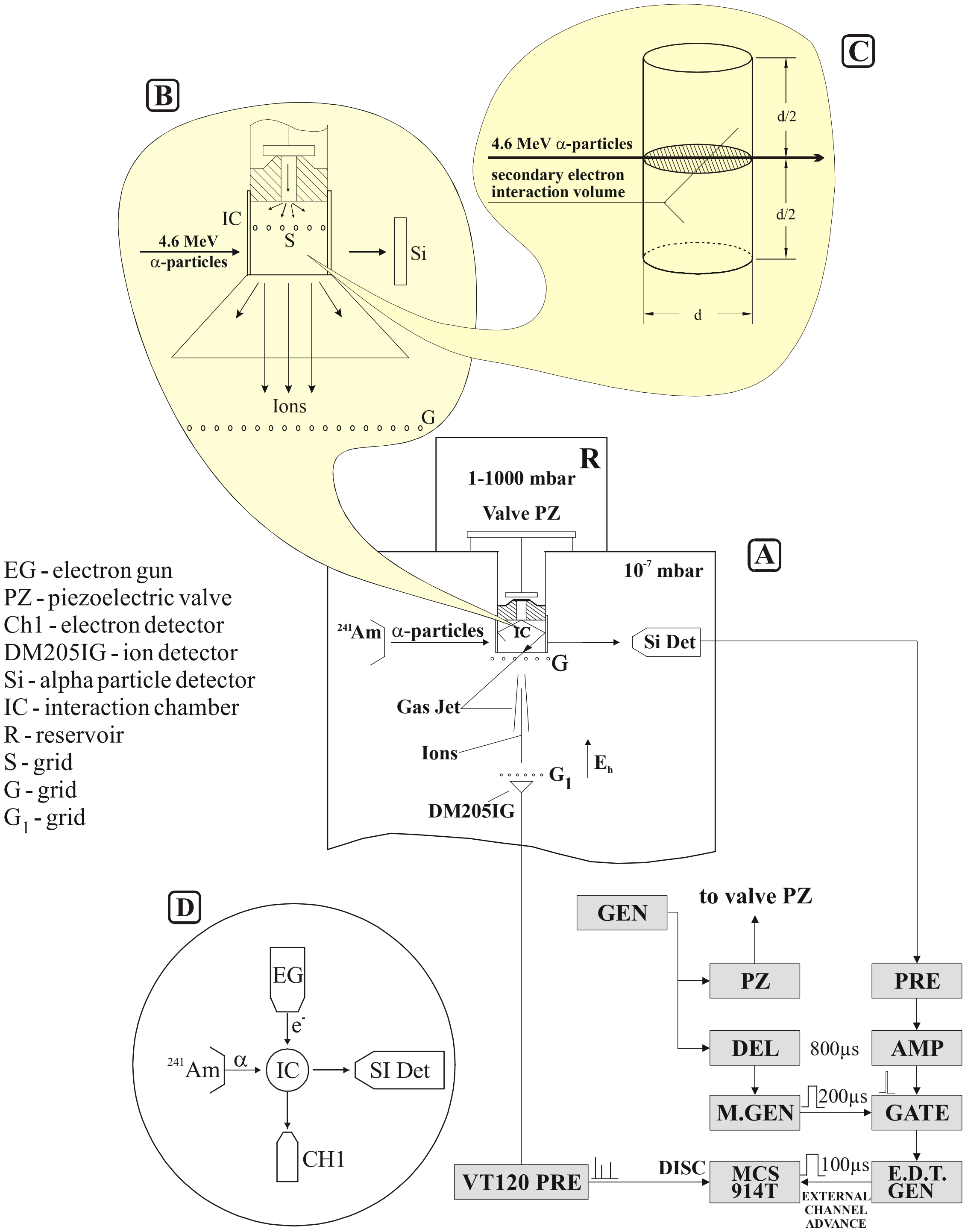


Figure 1. Schematic view of the Jet Counter: A- configuration for the experiments with alpha particles, B- sensitive volume inside the interaction chamber, IC; C- schematic presentation of sensitive volume in unit density scale with irradiation geometry. D- cross section of Jet Counter through sensitive volume at beam line pattern, showing the positions of detectors. EG- electron gun; PZ- piezoelectric valve; CH1- electron detector, DM205IG- ion detector, Si – alpha particle detector, IC interaction chamber.

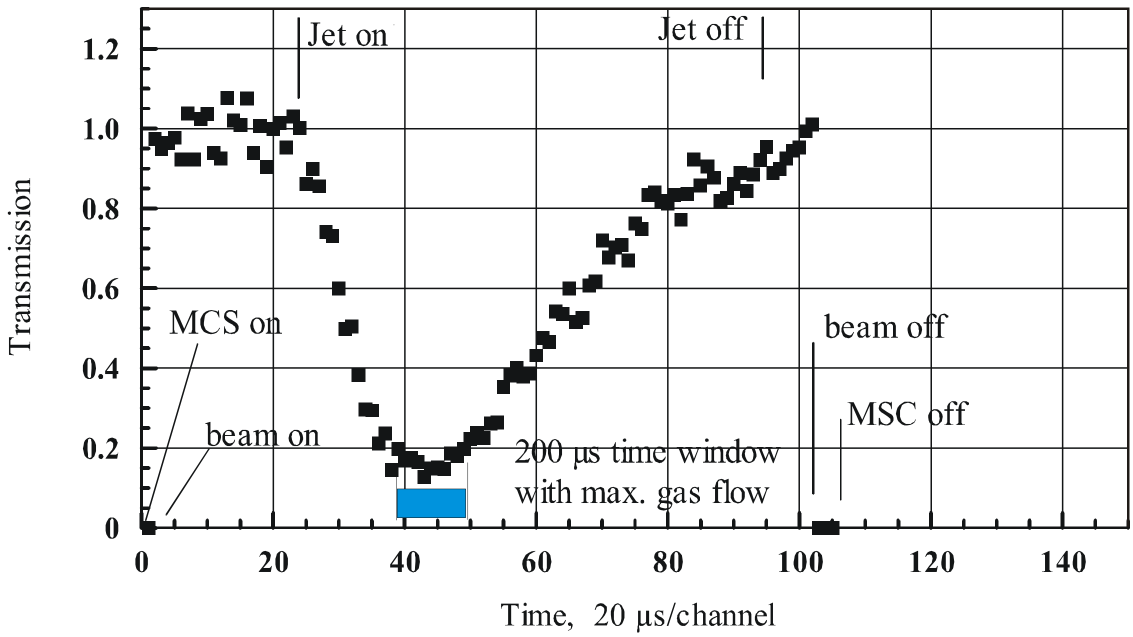


Figure 2. Transmission of 100 eV electrons through propane jets, timing chart, the time window 200 µs, (as gate on) .

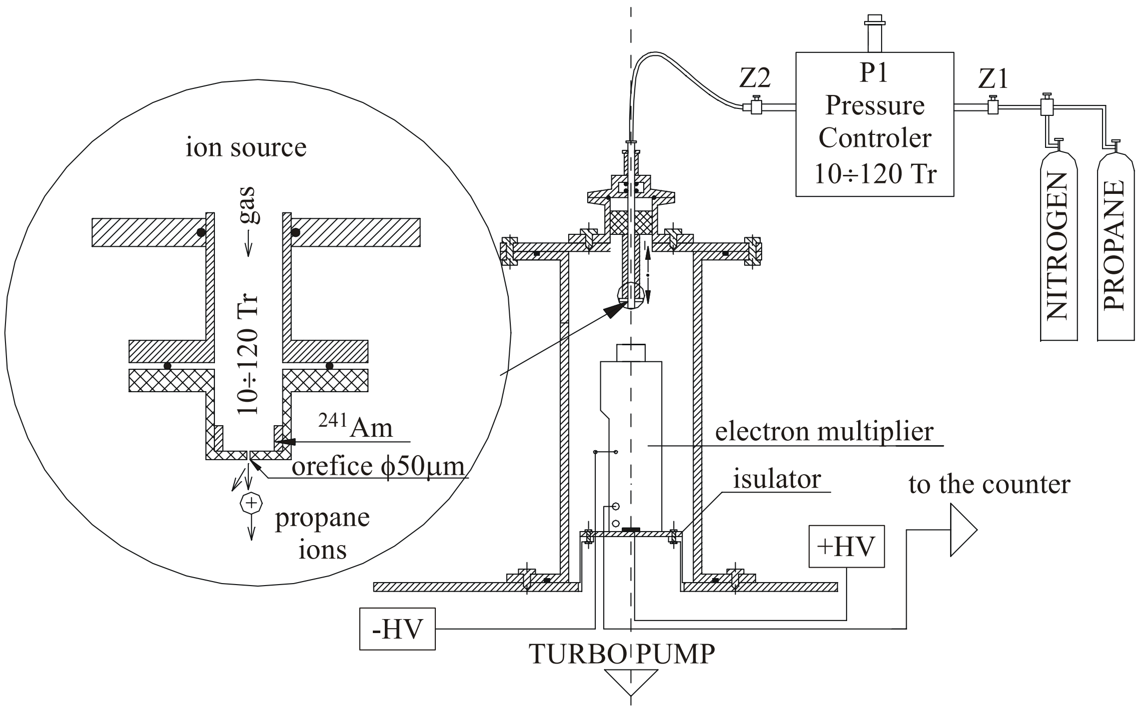


Figure 3. Schematic view of the set up for measuring of absolute efficiency of the ion detectors. Enlargement the propane ion source.

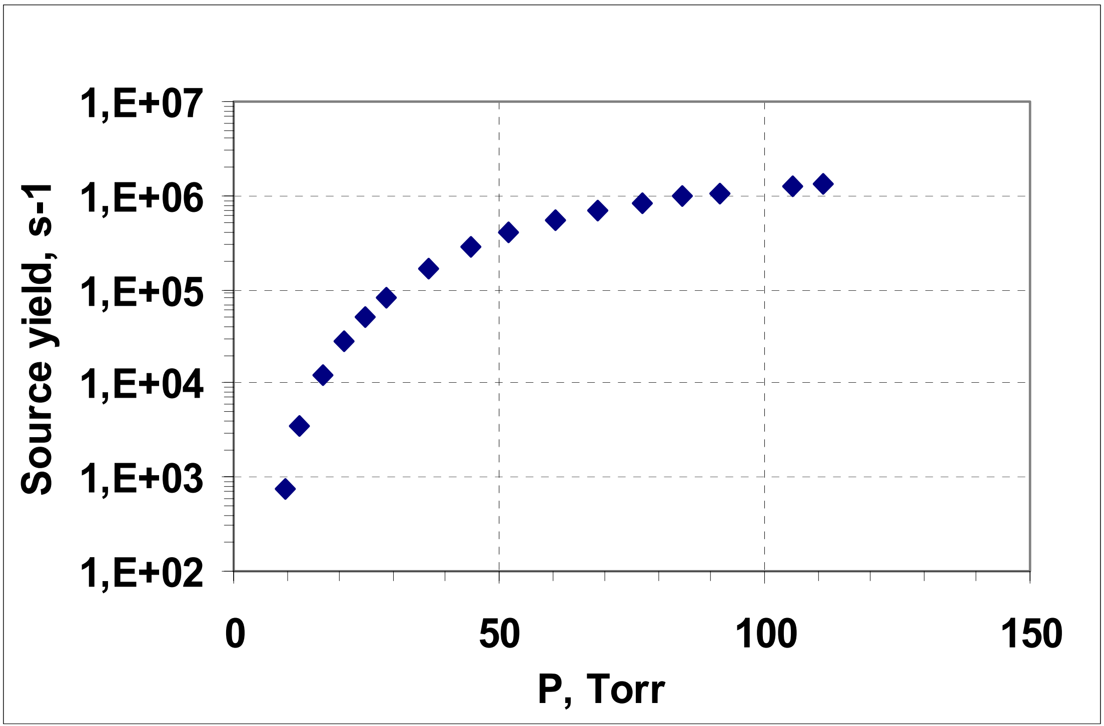


Figure 4. The yield of the propane ion source.

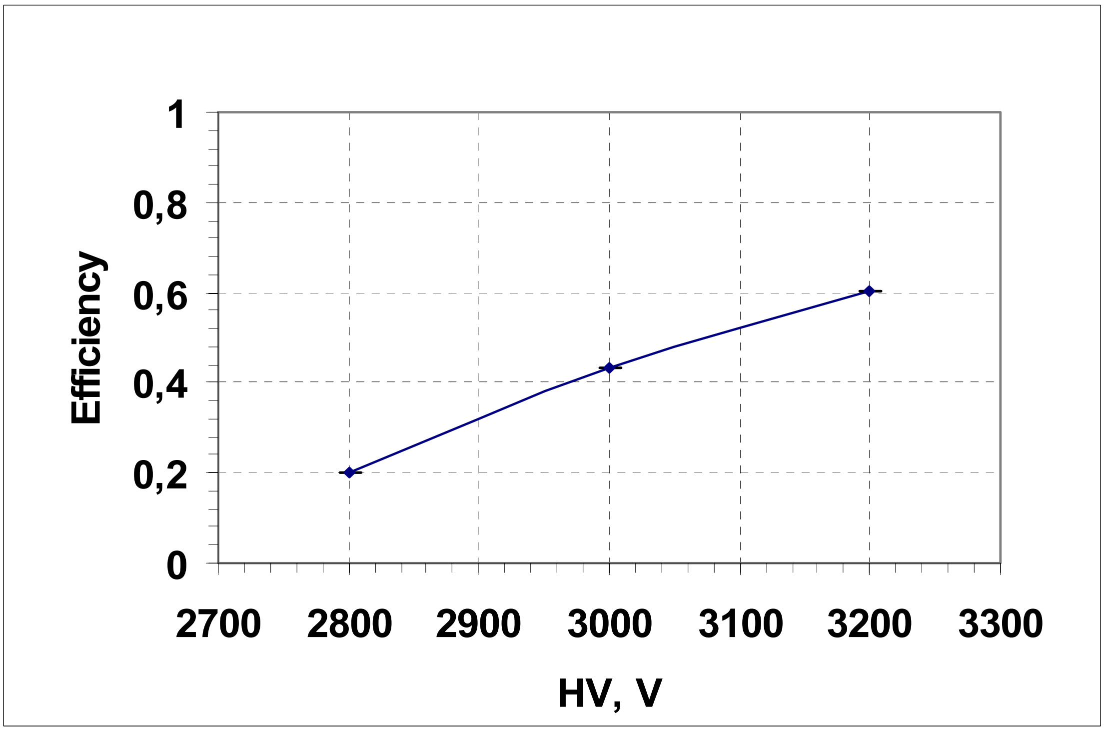
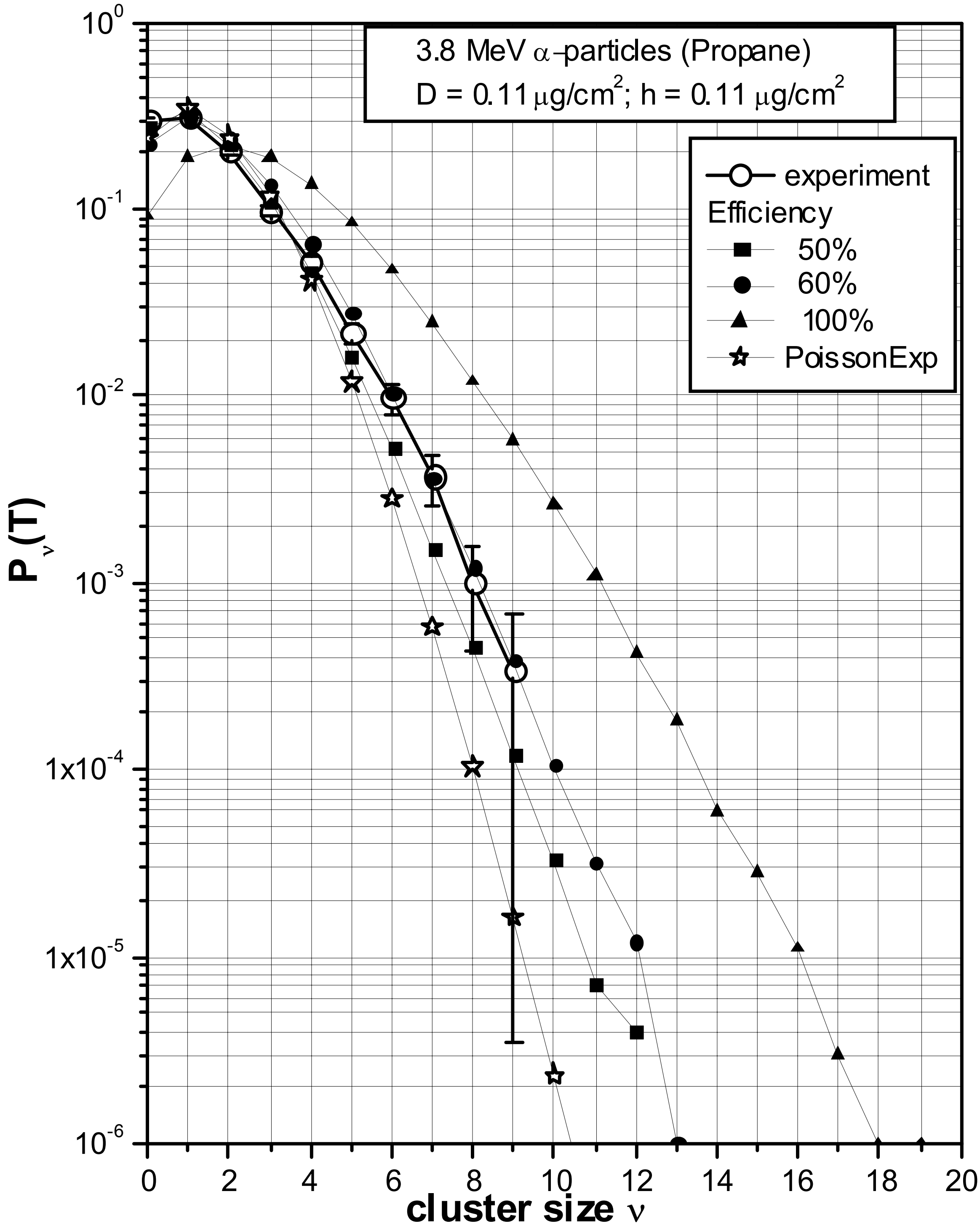
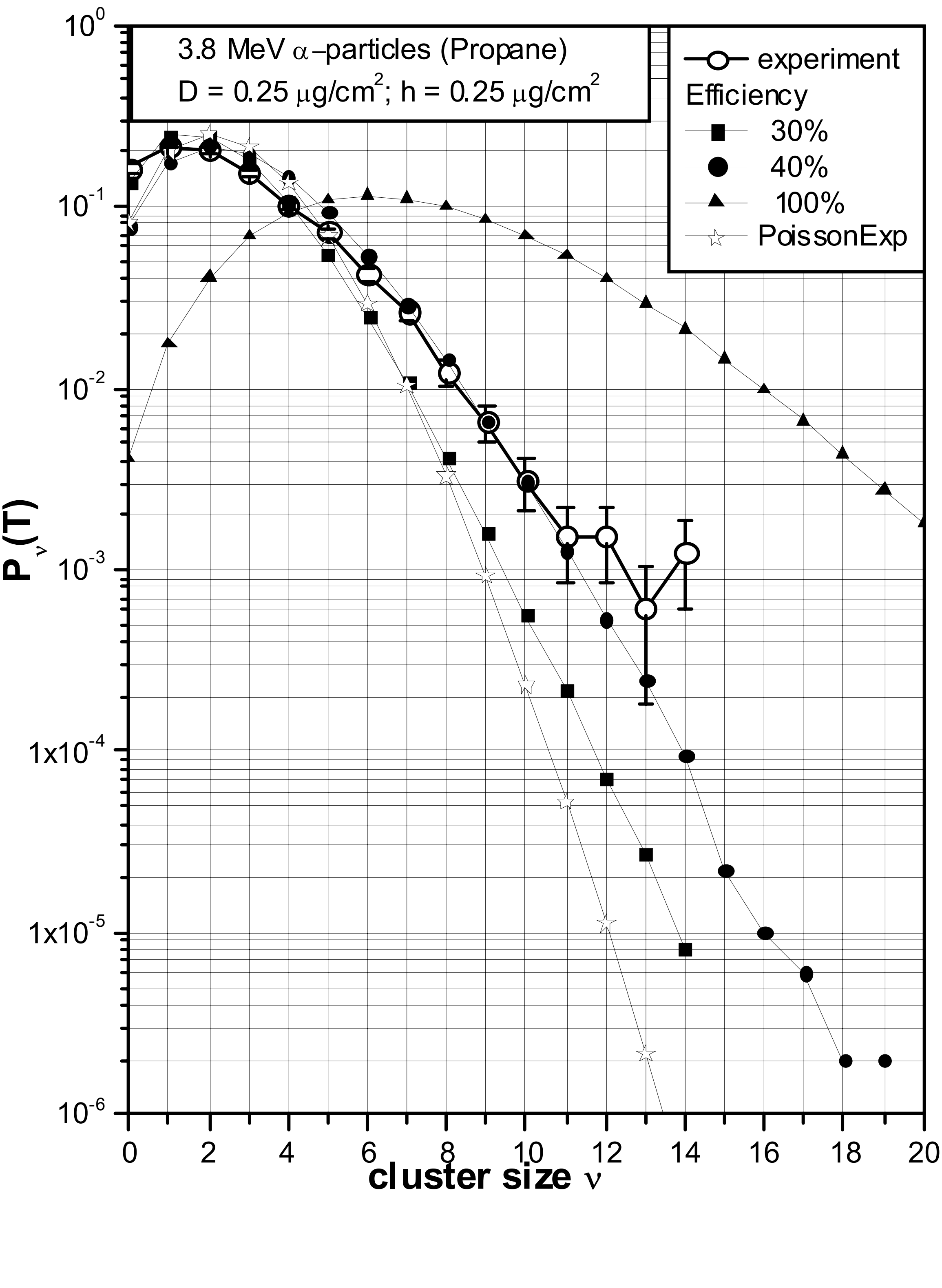


Figure 5. Efficiency of propane ion registration by the ion detector used in the experiment.



3.8 MeV α-particles (Propane)
D = 0.11 μg/cm²; h = 0.11 μg/cm²
experiment
Efficiency
50%
60%
100%
PoissonExp
P_ν(T)
cluster size ν
10^0
10^-1
10^-2
10^-3
1x10^-4
1x10^-5
10^-6
0
2
4
6
8
10
12
14
16
18
20



3.8 MeV α–particles (Propane)
D = 0.25 μg/cm²; h = 0.25 μg/cm²
experiment
Efficiency
30%
40%
100%
PoissonExp
P_ν(T)
10^0
10^-1
10^-2
10^-3
1x10^-4
1x10^-5
10^-6
0 2 4 6 8 10 12 14 16 18 20
cluster size ν

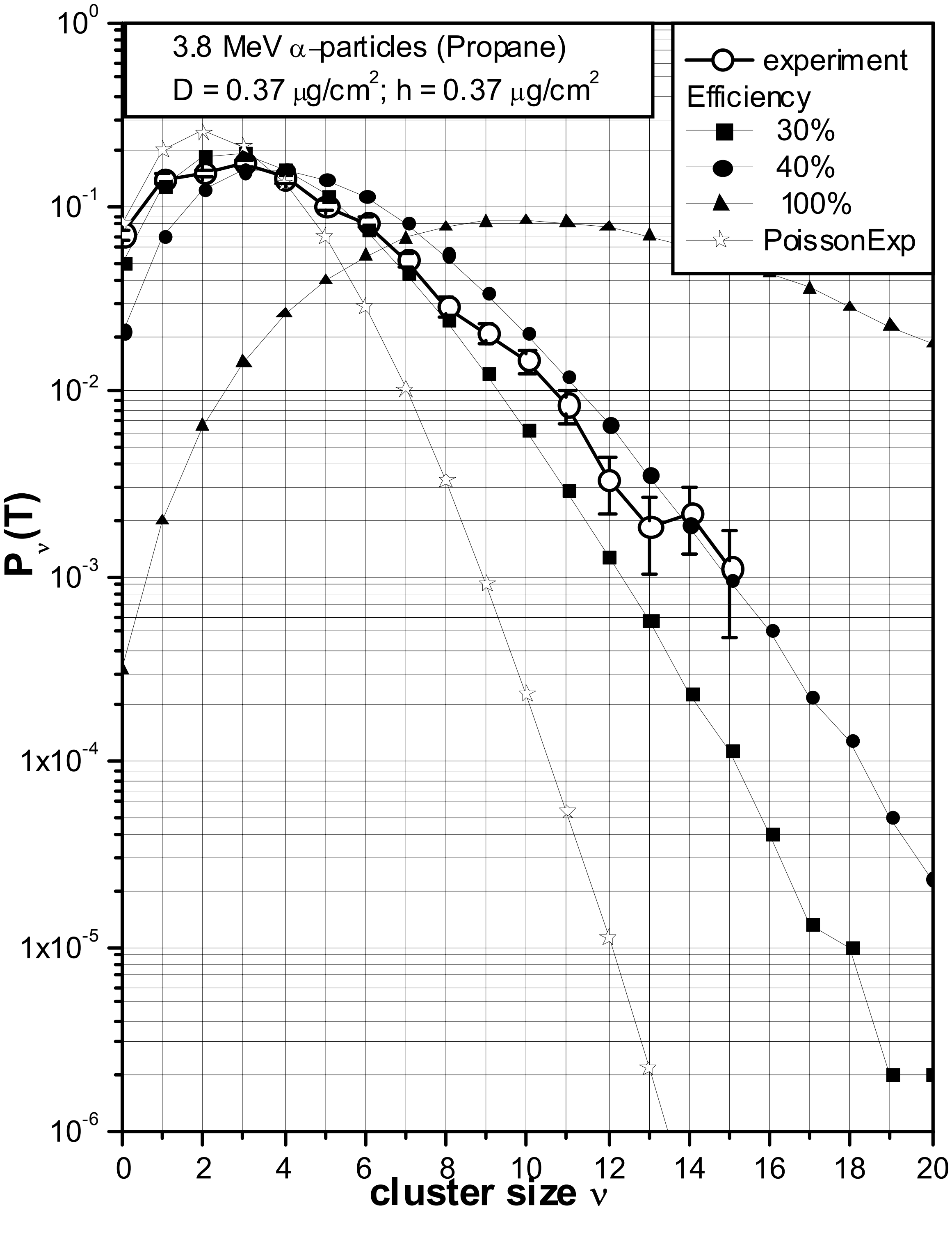


Figure 6. Frequency distribution spectra for different diameters of sensitive volume irradiated by 3.8 MeV alpha particles. Open circle – experimental spectra, full cicle and squares Monte Carlo calculations for different ion detector efficiencies, stars - Poisson distribution, full triangle - calculated true distribution of ionization clusters