ITEP-38-98

Institute of Theoretical
and Experimental Physics

FERMILAB
MAR 22 1999
LIBRARY

38-98

REGISTRATION PARAMETERS OF POLYETHYLENETEREPHTHALATE DETECTOR DEFINED FROM TRACKS OF IONS AFTER ADDITIONAL EXPOSURE BY HOMOGENEOUS GAMMA-RADIATION FOR DIFFERENT ETCHING TEMPERATURES.

Fermilab Library
0 1160 0062342 5

Moscow 1998

UDK 539.1 M-16

REGISTRATION PARAMETERS OF POLYETHYLENETEREPHTHALATE DETECTOR DEFINED FROM TRACKS OF IONS AFTER ADDITIONAL EXPOSURE BY HOMOGENEOUS GAMMA-RADIATION FOR DIFFERENT ETCHING TEMPERATURES:
Preprint ITEP 38-98/

V.A.Ditlov - M., 1998 - 16p.

In frame of many-hits model of local response there were found registration parameters of polyethyleneterephthalate detector from experiment with **Ar** and **Xe** tracks after set of additional γ-exposures for two temperatures of etching. There were used experimental information about etching rate along the track - V_t , and etching rate of unexposed material of detector - V_b . There were obtained the dependencies of response function V_t/V_b on γ-dose for different ions and different etching temperatures There was shown a possibility of decreasing of the registration threshold in direction of low ion atomic number Z.

В рамках модели многих ударов появления локального отклика были найдены регистрационные параметры полиэтилентерефталата, используемого в качестве детектора. С этой целью использованы экспериментальные значения собственных скоростей травления материала V_b и скоростей травления V_t вдоль треков ядер **Ar** и **Xe** после дополнительной γ-экспозиции для двух температур травления. Получены зависимости функции отклика V_t/V_b от γ-дозы для различных ионов при различных температурах травления. Показана возможность уменьшения порога чувствительности в сторону меньших атомных номеров регистрируемых ионов Z.

Fig. - 17, ref. - 10 name.

© Институт теоретической и экспериментальной физики, 1998

Introduction.

We shall consider a phenomena when the polymer detector with latent ion tracks was etched at different temperatures after additional γ-exposure. The aim of this work is to built up a method of a definition of registration parameters from experimental dependencies of etching rate on the value of γ-exposure.

Then we consider a track registration close to threshold of registration for ions with small atomic numbers. We shall give an appreciation of possibility to register α-particles after additional exposure by γ-rays in an energy interval of a-particles, used in radon study. This work was reported at two conferences devoted to radon dosimetry [1-2]. -

Experimental data .

We used experimental results of work [3]. There were given dependencies Vt/Vb on γ-dose exposure for tracks of **Ar** - 7.6 MeV/amu, etched at T=50^0 C and **Xe** with E=0.75 Mev/amu etched at T=30^0 C in polyethyleneterephthalate (PETP). This
γ-exposure was made after an exposure by quick ions and with further keeping the detector in open air during thirteen days. V_t - etching rate of tracks, V_b - a bulk etching rate.

Calculation method.

Our approach was based on the next assumptions :

1. Polymer detectors consist of a majority of sensitive microscopic volumes [4-5].
2. Sizes a_0 of these volumes are so small that there are large fluctuations of act interactions of quick ions with atoms of matter inside it with mean value ξ_{ion} [6].
3. The sensitive volume can be in one of two states - " Yes" or "No" [4-6].
4. After threshold number "v" of effective interaction acts inside one sensitive volume it changes state "No" for a state "Yes" according to Poisson statistic [6]:

$$P_v^+(\xi)=1-\sum_{i=0}^{v-1}\frac{\xi^i}{i!}\cdot e^{-\xi} \qquad (1)$$

5. The mean value ξ_{ion} produced by any ion inside one sensitive volume [5] may be expressed by stopping power of quick ion dE/ds:

$$\xi_{ion}=(dE/ds)/(dE/ds)_0 \qquad (2)$$

where (dE/ds)$_0$ is a characteristic stopping power. For an approximate consideration δ-electrons with help of restricted energy losses REL_w [7] one has to use characteristic $(REL_w)_0$ [8] :

$$\xi_{ion}=REL_w/(REL_w)_0 \qquad (3)$$

The frequency of effective events produced by γ-rays was expressed by:

$$\xi_\gamma=D_\gamma/D_0 \qquad (4)$$

D_0-characteristic dose, a measure of effective events invoked in separate sensitive volume [4].

Listed above points are the body of a many-hit model [4-6]. We shall add the next :

6. Etching rate depends on probability of local response of sensitive microscopic volume by linear manner. There were considered two possibilities :

Version 1.

$$V_t(s)=V_b+C\cdot P^+_v(\xi)\ ; \qquad (5)$$

$$\xi(s)=\xi_{ion}(s)+\xi_\gamma \qquad (6)$$

Version 2.

$$V_t(s)=C\cdot P^+_v(\xi) \qquad (7)$$

$$\xi(s)=\xi_b+\xi_{ion}(s)+\xi_\gamma \qquad (8)$$

where ξ_{ion} - a number of effective events produced by quick ion and ξ_γ- number of effective events produced by γ-quanta inside one sensitive microvolume. S is a residual range of registered quick ion. "C" is some constant value.

Version 1 is an usual way to consider V_b of any material. Version 2 is based on the supposition, that the etching rate V_b exists due to spontaneous transition of some part of the sensitive microscopic volumes from state "No" to state "Yes" [9] and that this transition is invoked by some hypothetical homogeneous background radiation, included in (8) through ξ_b, number of effective events produced by this radiation.

7. Parameters C, $(dE/ds)_0$ or $(REL)_0$, D_0 and ξ_b depend on etching temperature through the expression of the Arhenius distribution kind:

$$f(\varepsilon,T) = A\cdot e^{-\frac{\varepsilon}{kT}} \qquad (9)$$

Thus, here in our approach the registration parameters of any polymer detector are - v, $(dE/ds)_0$ or $(REL_w)_0$, C, D_0. According to (9) last three parameters for each T may be expressed through own pair of parameters (A,ε).

For our versions of V_b we can write two functions of mean square differences j_{max} between experimental points and calculated $V(D_{\gamma,j})$ values for these points of γ-rays doses.

For version 1: $$F(\nu,\xi_{ion},D_0)=\sqrt{\sum_{j=1}^{j_{max}} B_j\left[V_{t,j}-V_b-C\cdot P_\nu^*(\xi_{ion}+\xi_{\gamma,j})\right]^2} \quad \text{with} \quad B_j=\left|V_{t,j}-V_b\right|/\sum_{i=1}^{j_{max}}\left|V_{t,i}-V_b\right|^3. \qquad (10)$$

For version 2: $$F(\nu,\xi_{ion},D_0)=\sqrt{\sum_{j=1}^{j_{max}} B_j\left[V_{t,j}-C\cdot P_\nu^*(\xi_b+\xi_{ion}+\xi_{\gamma,j})\right]^2} \quad \text{with} \quad B_j=V_{t,j}/\sum_{i=1}^{j_{max}} V_{i,j}^3 . \qquad (11)$$

Registration parameters.

We built up algorithms for searching minimums of functions (10) and (11) by changing parameters ξ_{ion}, D_o and ν with variable steps in large value intervals. The results are shown at in Table 1 and figures 1-4. It is difficult to show at the same figure the differences between fits of our two Versions due to their smallness. The accuracy of fits for both versions is demonstrated by $F_{min}(\nu)$ shown at figures 5-6. We repeated our search of registration parameters with different restriction energy "w" in REL_w and found that the results depends on "w" very weekly. From (9) and Table 1 we got results in Table 2.

Table I. Registration parameters of the 3-hit model for two versions of V_b consideration.

	1	2	3	4	5	6	7	8	9	10	11
№	Exposure kind	MeV/amu	T°C	F_{min} %	ν	C μm/h	ξ_{ion}	$(dE/ds)_0$ MeV/μm	D_o Mrad	ξ_b	a_o μm
1.1	γ-rays Version 1			3.37	3	0.76			43.95	2.562	
1.2	γ-rays Version 2			5.98	3	2.56			284.3	0.108	
2.1	Argon Version 1	7.6	50	3.85	3	80.50	1.07	1.77	2.89	0.324	0.084
2.2	Argon Version 2			3.85	3	80.82	0.771	2.47	2.88	0.323	0.099
3.1	γ-rays Version 1			27.2	3	0.28			97.23	1.125	
3.2	γ-rays Version 2			16.9	3	0.37			227.6	0.955	
4.1	Xenon Version 1	0.75	30	3.82	3	30.6	1.610	4.60	0.37	0.187	0.379
4.2	Xenon Version 2			3.82	3	0.66	1.426	5.20	0.37	0.187	0.402

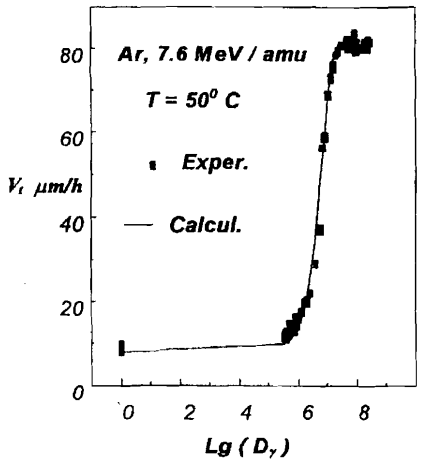


Fig.1 Dependence V_t (D_γ), etching T=50°C, for Ar with E=7.6 MeV/amu

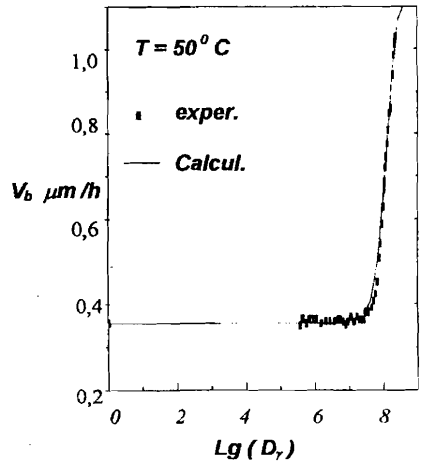


Fig.2 Dependence $V_b(D_\gamma)$ for etching T=50° C .

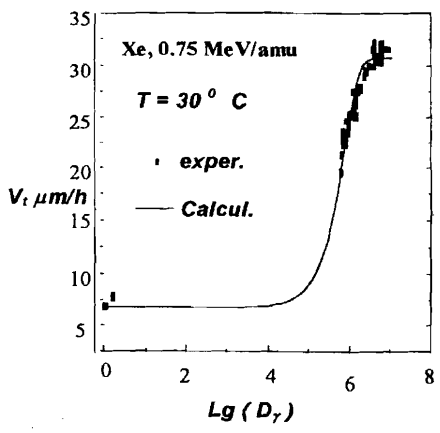


Fig.3. Dependence Vt (D_γ) , etching T=30° C for Xe with E=0.75 MeV/amu

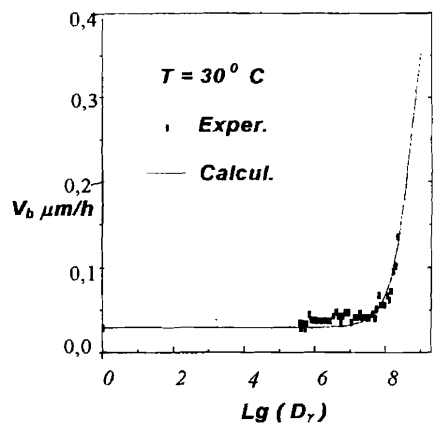
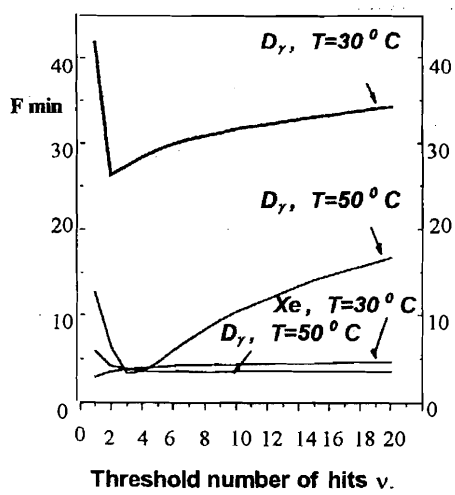


Fig.4. Dependence $V_b(D_\gamma)$ for etching T=30° C



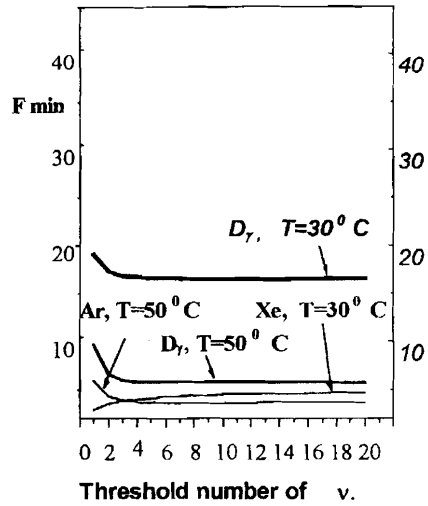


Fig.5. Version 1.
Behavior of fitting error $F(\nu)$.

Fig.6. Version 2.
Behavior of fitting error $F(\nu)$.

Table II. Coefficients for temperature dependencies of registration parameters of the polymer film PETP.

The values presented as:	Version I $V_t = V_b + C \cdot P_\nu^+(\xi)$		Version II. $V_t = C \cdot P_\nu^+(\xi_b + \xi)$	
$A_0 \cdot e^{-\frac{\varepsilon}{kT}}$	A_0	ε (eV)	A_0	ε (eV)
C (μm/h) in the track.	1.927E+08	0.4085	1.874E+08	0.4978
$(dE/ds)_0$ keV/μm	3.124E-02	-0.3138	9.485E-04	-0.4018
$D_{0\gamma}$ (rad) in the track.	8.788E+19	0.8638	9.485E+19	-0.8659
ξ_b in the track.	433.0E+00	0.2308	407.8779 0	0.2292
C (μm/h) out of the track	1.776E+15	0.9394	2.746E+06	0.4201
$D_{0\gamma}$ (rad) out of the track	8.289E+09	0.0938	2.743E+03	-0.3334
ξ_b out of the track	666180.E0	0.3469	21.30045	0.1087
a_0 (μm.)	1.460E-11	-0.6238	8.38E-11	-0.5797

Examples of calculations.

Knowing registration parameters one can calculate various functions. Fig. 7 presents dependencies *Vt (E,T)/Vb(E,T)* for ions used in the experiment. Fig. 8 shows V_t/V_b of Version 1 as a functions on Z and *E=100* Mev/amu for set of T^0.

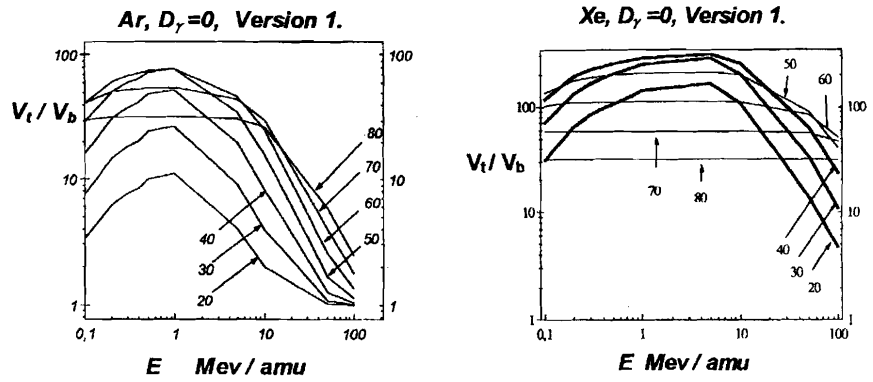


Fig.7. Version 1. *Vt(E,T)/Vb(E,T)* for **Ar** and **Xe** tracks etched at temperatures shown by arrows. *Dγ=0.*

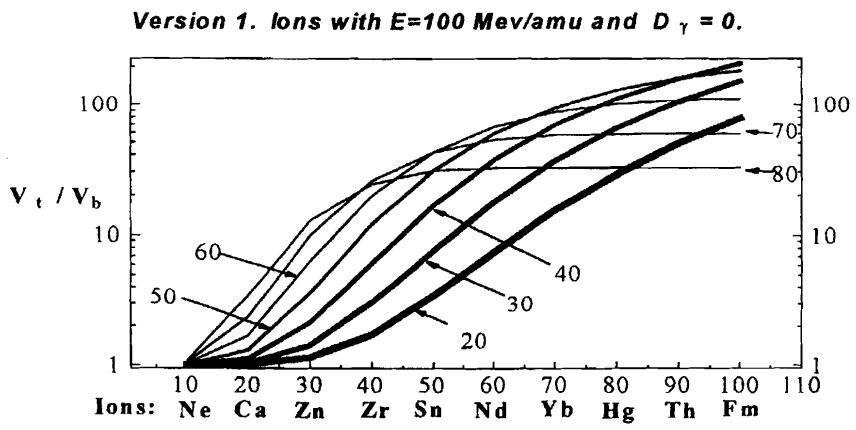
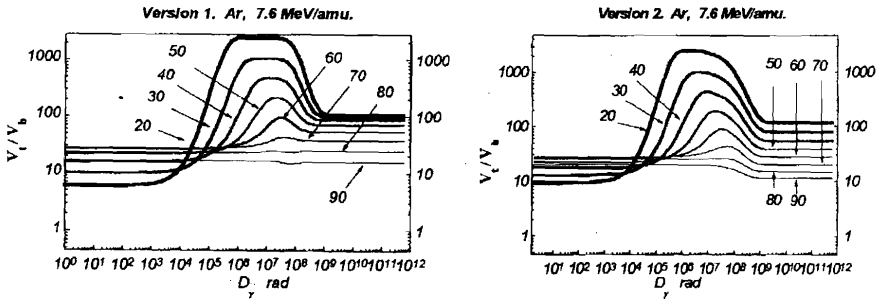


Fig.8 $r=V_t/V_b$ as a function on atomic number of an ion with energy *E=100* MeV/amu.

Recalculation for new temperatures.

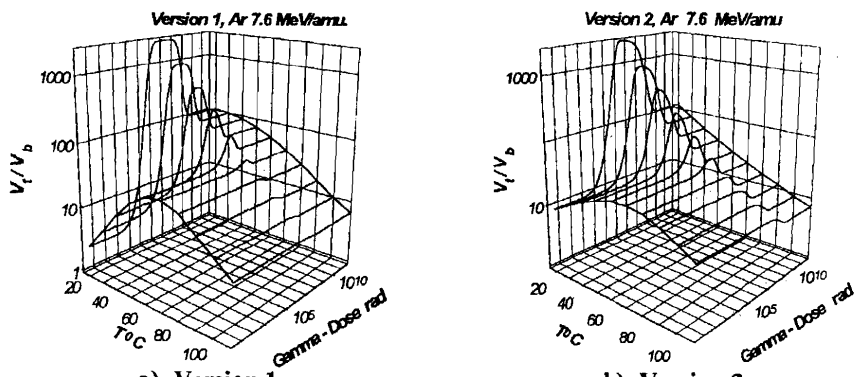
Figures 9-12 present calculated relations $r = V_t/V_b$ as functions on γ-dose at different treatment temperatures for **Xe** and **Ar** at energies of the experiment [3] for two versions of V_b consideration. V_t is etching rate along the ion track, V_b is a body etching rate.

These figures show, that at small γ-exposures the relation r=Vt/Vb grows up and then it goes through a maximum and falls down to a plato. The right parts of curves are coincident for both ions **Ar** and **Xe** at each treatment temperature. The calculations for other atoms and energies confirm, that this region does not depend on ion atomic number and energy. At the same time the parts of curves to the left from the maximum, are different for different ions and energies. It means, that an ion



a) Version 1. **b) Version 2.**

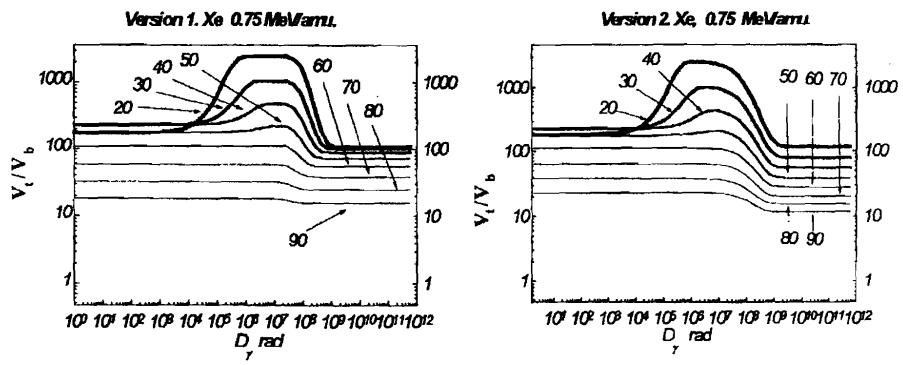
Fig.9 Dependence $r = V_t(D_\gamma)/V_b(D_\gamma)$ for **Ar.**



a) Version 1. **b) Version 2.**

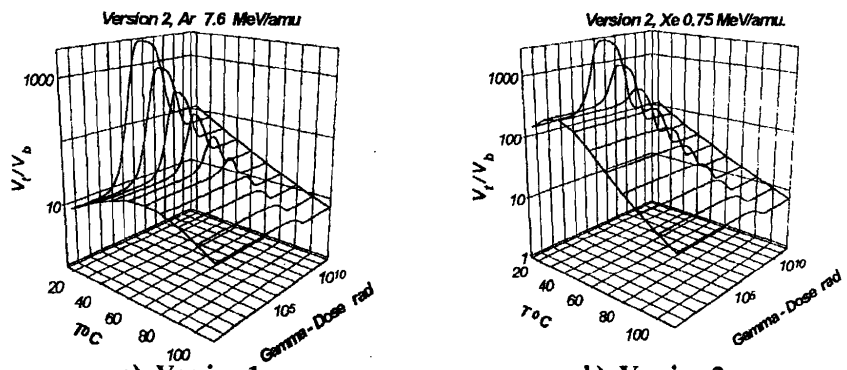
Fig.10 Dependence $r = V_t(D_\gamma)/V_b(D_\gamma)$ for **Ar** in three-dimensional presentation.

discrimination possibility of our detector is decreasing with increasing of γ-exposure dose D_γ. Any exposure by γ-dose destroys information about ion parameters and after V_t/V_b maximum there takes place a phase transition and a volume inside the latent track works as "Yes-No" detector. The discrimination possibility of the detector falls to zero. Fig. 13 shows the discrimination possibility as a relation of two etching rates V_t of ions **Ar** and **Xe**. For other atoms and energies it will be the same behavior.



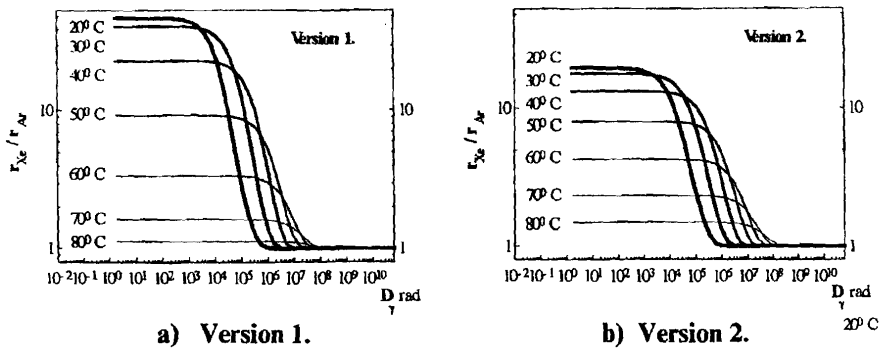
a) Version 1. **b) Version 2.**

Fig.11. Dependence $r=V_t(D_\gamma)/V_b(D_\gamma)$ for **Xe**.



a) Version 1. **b) Version 2.**

Fig.12. Dependence $r=V_t(D_\gamma)/V_b(D_\gamma)$ for **Xe** in a three-dimensional presentation.



a) Version 1. **b) Version 2.**

Fig.13. Behavior of discrimination possibility of detector with gamma-exposure increasing for two ions **Ar** and **Xe** with energies from mentioned experiment

A case of low atomic numbers.

It is a more interesting case for application of the method post-exposure by γ-dose, especially for the case of α-particles of radon study. Figures 14-15 shows calculated r=Vt/Vb dependencies on γ-exposure for α-particles with energy 100 MeV/amu. We can see, that for both versions of calculations the left shoulders of dependencies lay on horizontal line with r=1 without any selectivity of track etching.

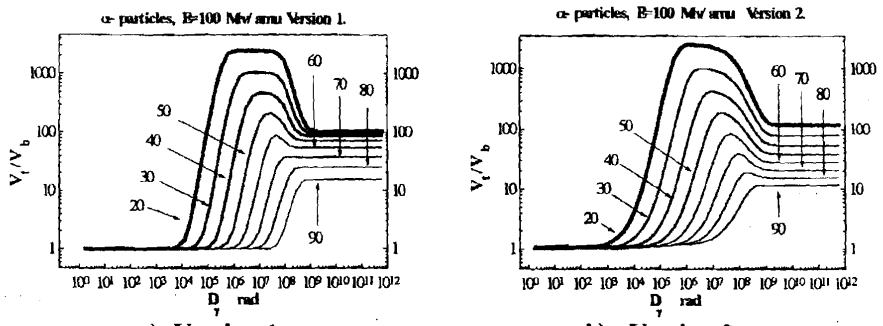
But from the exposition D_γ ~10 Mrad they are growing up to the same maximum values, as at figures 9-12. It is a very important phenomena as it means that we can register α-particles with high energy in PETP detector using additional γ-exposure.

The threshold value.

The ion with lowest atomic number **Z** to be registered in PETP detector is known as 4 at etching temperature T=60° C [10]. So we can estimate the lowest values of γ-dose at which tracks of α-particles became etchable for energies of radon study. In order to study this region of **Z** we have to use two additional threshold parameter connected with our possibility to observe track opening after etching. The first one is a minimal relation $r_{min}=V_t/V_b$ and the second is a minimal length of track L_{min}. We suppose, that

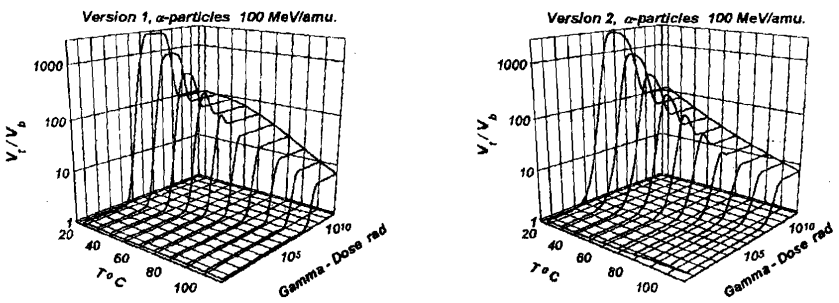
$$r_{min}=2 \qquad (12) \qquad \text{and} \qquad L_{min}=20\ \mu m \qquad (13)$$

The energy for the range L_{min} is about 1 Mev/amu. (After etching visible lengths of such tracks ~ 10 μm.). Knowing registration parameters of polymer



a) Version 1. **b) Version 2.**

Fig.14. V_t/V_b as function on Dγ for α-particles, E=100 Mev/amu



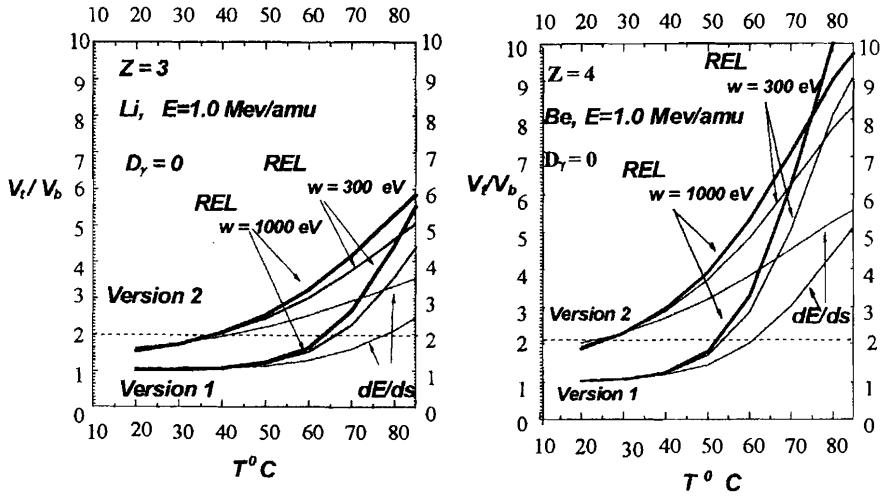
a) Version 1. **b) Version 2.**

Fig.15. V_t/V_b as function of γ-ray exposure Dγ for α-particles with E=100 Mev/amu in three-dimensional presentation.

detector we can calculate the case near registration threshold without any additional γ-exposure at any treatment temperature. At the fig. 16 we presented calculated dependencies $r(T) = V_t/V_b$ for two ions **Li** and **Be** with E=1 MeV/amu. Both versions 1 and 2 are designed by appropriate arrows .

In according to two versions of consideration there are two groups of curves at the fig.16. Each group contains three curves. One curve is calculated with help of stopping power *dE/ds*, eq. (2) and two others were calculated with help of restricted energy losses REL_w , eq. (3) with two different cut off energy w= 300 and 1000 eV. The group of version 2 is situated at both figures upper than the groups of curves, calculated for version 1, except of a regions of high values T^0 in the shown temperature interval. The level r_{min} =2 is marked by horizontal dashed lines.

As we can see from fig.16-a the curves of version 2 for **Li** lay higher than the line of threshold level in temperature region T ≥ 40⁰C. It is in contradiction with experimental data [10]. The same we can see for two curves of the first version calculated for **Li** at the base of REL_w for the temperature region T ≥ 65⁰ C. Only one curve obtained for **Li** with help of stopping power, eq. (2) of version 1 shows, that at these temperatures track of 1 MeV/amu **Li** can not be etched without any additional γ-exposures.



a) **Li** . b) **Be**.

Fig.16. V_t / V_b as a function on etching temperature for **Li** and **Be** after two versions of calculations with different restriction energy "w" of δ-electrons and without any additional exposures by γ-rays.

At the fig. 16-b for **Be** with 1 Mev/amu we can see, that curves of version 2 are upper than the threshold line r_{min}=2 and the track of **Be** should be etchable in whole temperature interval greater T=20⁰ C. In reality it is not so. The curves of version 1, calculated with help of REL_w show, that the track of **Be** will be etchable for treatment temperatures grater than T=50⁰ C. It is not in accordance with known experimental information, as at the practice this track may be etched at temperatures T ≥ 60⁰C. Thus, our calculations showed that the version 1 used with equation (2) is in more good accordance with known experimental [10] data and we can choose this version and ξ_{ion}=(dE/ds)/(dE/ds) $_0$ for further calculation.

Tracks of alpha-particles.

Radon measurements with help of any polymer detectors is possible if this polymer is capable to register α-particles. At the fig.17 the response function dependencies *r(E)* on α-particle energy is presented in interval to 0.5-6 Mev/amu for five values of γ-dose exposure: 1, 3, 5.2, 9.1, 16 Mrad. It is seen from the fig.17, that additional exposure by γ-rays with D_γ=1 Mrad is insufficient to do latent α-particle track etchable, but other four exposures have to give us desirable effect.

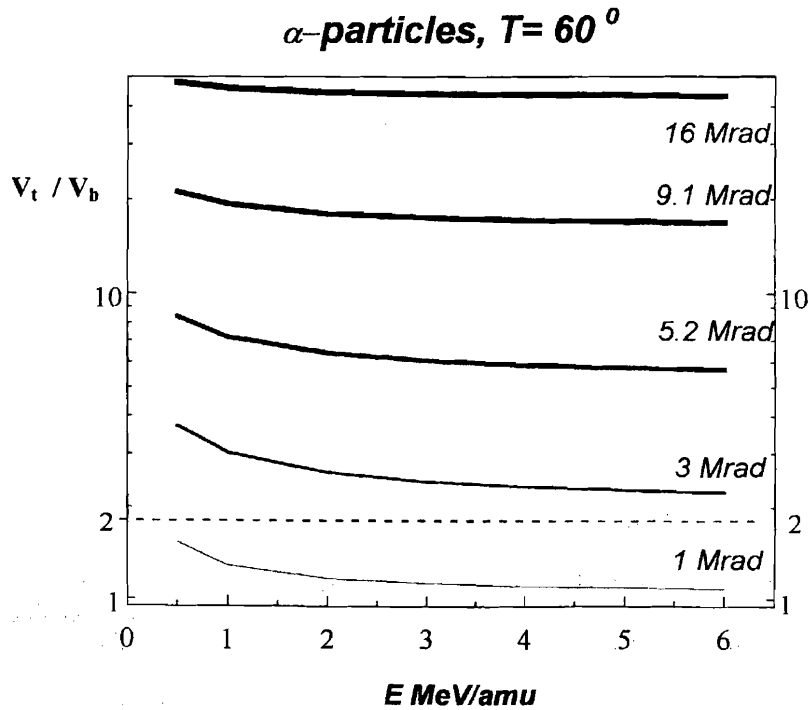


Fig.17. Dependence V_t/V_b on energy for α-particles calculated for set of post γ-exposure in version 1 with utilization of stopping power in (2).

Conclusions.

The process of the track visualization after γ-dose exposure goes through two stages. The first one is a stage of oxidization during thirteen days and the second stage of the process is the etching. Relation Co_{track}/Co_{bulk} equals 105-109 for both temperatures and for both ions **Ar** and **Xe.** It is possible if inside of ion track core we have phase transition increasing number of sensitive volumes in one hundred times. The second stage of the visualization process is usual process of etching.

In maximum of response function after additional γ-exposure volume of track works as a separate "Yes-No" detector with weak discrimination possibility. So, it is reasonable to use methodology of large γ-exposure in those tasks, where the type of fast ions is known and it is need measure their number, for example.

Figures 1-4 demonstrate good possibilities of model of ν-hits response for a description of relation $r=V_t/V_b$ on γ-dose. The general behavior of the dependencies presented at figures 7-8 seems to be quite reasonable. For $\nu>3$ the fitting error of version 2 depends on registration parameter ν very weakly. Possibly, the detector has a wide distribution of sensitive volumes over this parameter in this region of γ-doses.

For high energies E and large **Z** it is need a special consideration of δ-electrons action [4-5] and our results are only preliminary. For more exact calculation first of all it is need put a special experiment for more wide interval of E and **Z**. and to measure radial etching rate [8]. From the point of view of δ-electrons consideration the eq. (2) with a stopping power dE/ds is a zero approximation, in which the role in track formation of δ-electrons with different energies is supposed the same, the eq. (3) with REL_w [7] is the first approximation, the approach of R.Katz [2] is a second one and our approach [5] with exact consideration of multiple scattering of δ-electrons provides the maximal level of accuracy.

In the work it was developed the calculation method of etching rate V_t and V_b dependencies on γ-dose for any etching temperatures and for any ions.

Our calculations pointed out at a possibility to register in PETP (lavsan) after additional γ-ray exposure ions with atomic number less than threshold value, known as Z=4 (**Be**). It needs an urgent experimental verification, but in case of a positive result radon measurements look like one of perspective application of this possibility as PETP has a set of unique properties, such as a cheapness, homogeneous and so on.

Relatively calculation method in whole we have to remember, that it was only a first approximation without detailed consideration of δ-electrons and that version 1 turned out to be better only in frame of this approximation. For more accurate study it is necessary to use another approach [5, 8], which demands more full experimental information than two parameters V_t and V_b.

REFERENCES

[1] Ditlov V.A. et al. Tracks of ions in solids after additional exposure by any kind of Homogeneous Radiation. In Abstracts *of 3rd International Colloquium on Rare Gas Geochemistry. December 10-14,1995,* Amristar, India, p.27.

[2] Ditlov V.A. Theoretical Dependencies of Response Functions Vt/Vb on additional gamma-exposure and etching temperature for polyeteleneterephthalate detector. In Abstracts *of Rare Gases Geochemistry IV International Conference, October 8-10, 1997*, Rome, Italy, p.70.

[3] Tretjakova S.P. and Mamonova T.I. "Influence of γ-rays to detecting properties of lavsan films". Preprint JINR, Dubna, 14-11439, 1978, 13 p.

[4] Katz R. Unified Track Theory. In Proceeding of *7th International Colloquium on Corpuscular Photography and visual solid detectors* Barcelona, 1970, p.1-29.

[5] Ditlov V. Theory of spatial calculation of primary action of δ-electrons in track detectors with account of multiple scattering. In *Solid St. Nucl. Track Detectors*. Eds H.Francois at al. Pergamon Press, 1980, pp. 131-141.

[6] Bogomolov K.S. La theorie fluctuatoire de l'action photographique des particules nucleares faiblement ionisantes . In: *Ergebnisse der Int. Konferenz f. wiss. Photographe*, Hellwich Koln, 1958, pp. 352-360.

[7] Benton E.V.,. *Charged Particle tracks in polymers. Criterion for track registration.* (US.Nav.Rad.Def., Lab:USNRDL-TR-76-80), Calif., 1967, 10 p.

[8] Ditlov V.A. et al..The Radial Etching velocity for tracks in polymer film. Nucl, Tracks Radiat. Meas., V.28, Nos 1-6, 1997. pp. 137-144.

[9] Ditlov V.A. Local response of sensitive microregion in solid state track detectors as a visualization result of some part of its physical states. Nucl, Tracks Radiat. Meas., V.22, Nos 1-4, 1993. pp. 105-111.

[10] U.P.Gangrskij et al. In: Registration and Spectrometry of Decay fragments. Moscow. Atomisdat. (1992), p-312