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NUCLEAR TRACK MEMBRANES IN DEVICES FOR AIR CLEANING, PERSONNEL VIABILITY SUPPORT AND BIOTECHNOLOGICAL PROTECTION

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Трековые мембраны в устройствах очистки воздушной среды, жизнеобеспечения персонала и биотехнологической защиты

Данная работа посвящена краткому изложению конструктивных разработок, созданных на основе трековых мембран в Лаборатории ядерных реакций ОИЯИ за последние несколько лет в области воздухоочистки. При использовании специфических, а зачастую и уникальных свойств трековых мембран были достигнуты определенные успехи в таких направлениях, как сверхтонкая очистка воздуха, воздухообеспечение локальных рабочих мест и ферментеров, защита органов дыхания человека от вредных аэрозолей и иммобилизация микроорганизмов в мембранных биореакторах. Изложены основные результаты испытаний разработанных систем и конструктивов, опубликованные в печати и доложенные на различных международных и всесоюзных конференциях и симпозиумах, а также получившие дату приоритета в международном реестре по патентам и изобретениям.

Работа выполнена в Лаборатории ядерных реакций ОИЯИ.

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Nuclear Track Membranes in Devices for Air Cleaning, Personnel Viability Support and Biotechnological Protection

This review briefly describes the designs developed in the last years in the Laboratory of Nuclear Reactions, JINR, on the basis of heavy-ion track membranes in the field of air cleaning. The specific and sometimes unique properties of the track membranes have allowed progress in such fields as very fine air cleaning, air supply to local work places and fermenters, protection of human respiratory organs against harmful aerosols, immobilization of micro-organisms in membrane bioreactors. Described are the main results obtained in tests of the systems and designs developed, which were already published and reported at various international and all-Union conferences and symposia, and which were given the date of priority in the international register of patents and inventions.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

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Introduction

The level achieved in production of computers, precise measuring instruments and automatic devices, the higher specific requirements to microclimate in medicine (sterile operation rooms) and in biotechnology (environment protection) make one concentrate on higher quality of air supply systems. Precise and sterile technologies require reliable and economic air conditioning and filtering systems, which are impossible without following certain standards. The most wide-spread quality standard for ecological safety of technologies is USA Federal Standard 209D, which is applied not only to clean rooms in the microelectronics [1,2] but also to other precise and sterile technologies, except for the cases when there are microbiological objects in the air, because it requires special dynamic control over microbiological contamination of the air.

Air cleanness classes defined by Standard 209D in relation to the size of particles and their number in a cubic foot are shown in the Table.

Membrane filters, such as nuclear track membranes [3,4] allowed a new approach to providing the necessary microclimate in precision and sterile processes. Producing no dust of their own, having smooth surfaces and high homogeneity of pores in size, track membranes of thin polyethylene terephthalate films allow non-traditional solutions to air supply problems.

The study of using track membranes for fine air cleaning and for keeping clean zones and technological volumes sterile has been carried out for several years at the Laboratory of Nuclear Reactions in JINR [5-16]. The present paper is a brief review of designs developed at the Laboratory.

Table. Federal Standard 209d

Class	Max number of particles /cft				
	≥0,1μm	≥0,2μm	≥0,3μm	≥0,5μm	≥5,0μm
1	35	7,5	3	1	-
10	350	75	30	10	-
100	-	750	300	100	-
1000	-	-	-	1000	7
10000	-	-	-	10000	70
100000	-	-	-	100000	700

1. Final air cleaning filter

In solving the problem of very fine air cleaning the emphasis was laid on getting the minimal intrapore surface of the track membrane and thus the minimal dust release from the surface. Being smooth, the membrane surface allows all production and storage microimpurities to be washed off easily. So, the filter design must be such that the washing liquid could freely go to the membrane surface and back. Here, the best is the tangent (along the surface) two-sided washing of the membrane, which increase the washing efficiency and makes it easier to dry the membrane in forced air flows.

In Fig.1 there are filtering plates with membranes. Their geometry allows tangent two-sided washing and drying of membranes in the assembly [10,11].

Owing to their positive properties the track membranes can be used for final air filtration when the air cleanness after preliminary cleaning (not worse than class 100, Table). ensures the required service life (1-2 years). However, since the straight cylindrical pores do not ensure a high filtration efficiency of particles smaller than the pore diameter, as we showed in ref.[5-9,12], one must be especially thorough in choosing the optimum pore diameter and hydrodynamic conditions of the air flow. Our investigations allowed us not only to find the efficiency limits of PET track membranes (not less than 99.0%) for micro- particles ≥

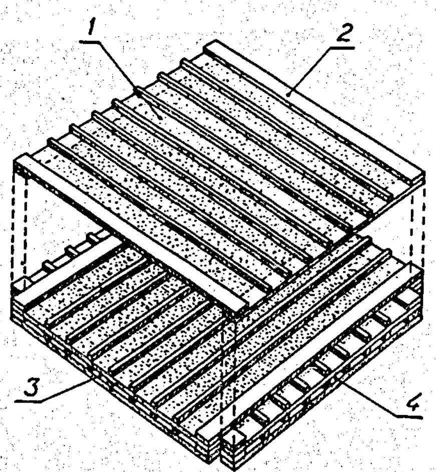


Fig.1. Separation plates of the filter module. 1 - track membrane; 2 - separation plate; 3,4 - air gaps of mutually perpendicular separation plates.

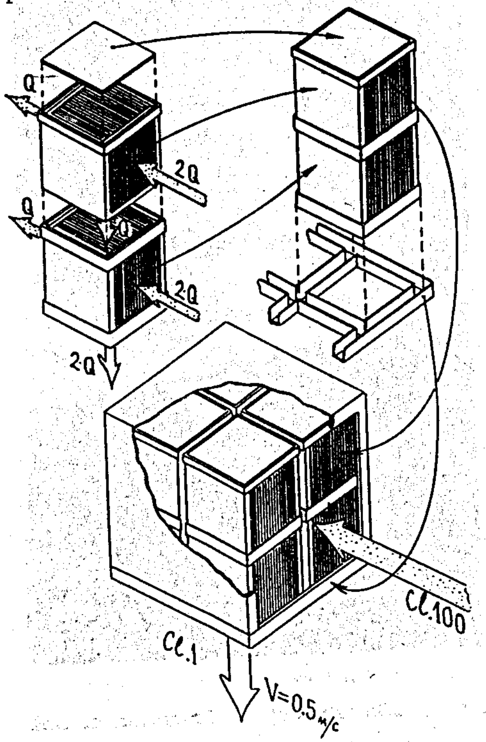
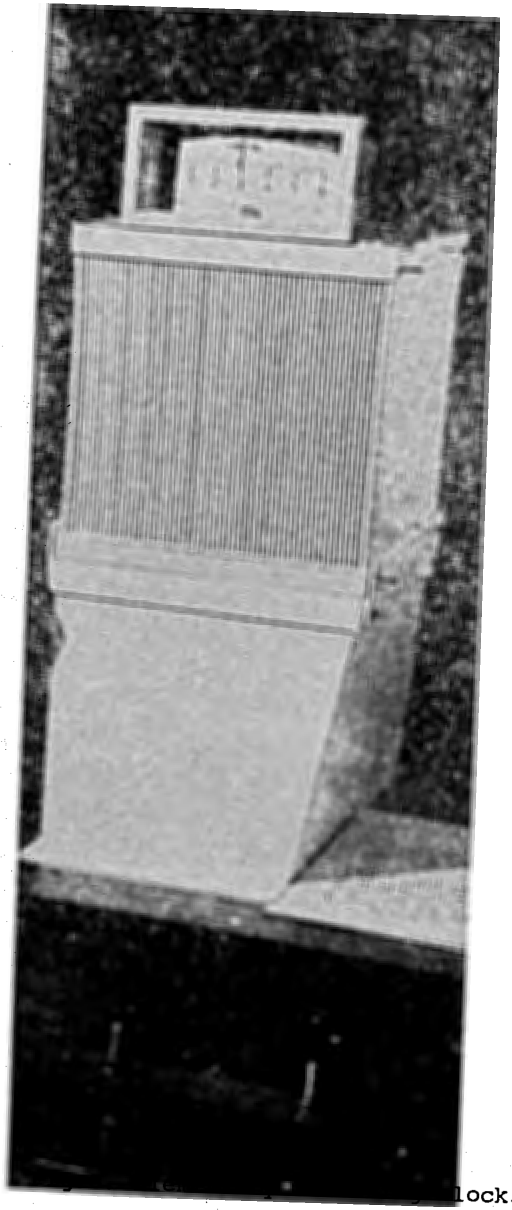


Fig.2. Schematic diagram of a filter assembly with 8 elementary blocks.



lock.

0.3 μm but also to estimate the acceptable working area of the membrane with allowance for the fan performance.

Fig.2 schematically shows the filter assembly comprising eight elementary blocks of filtering plates (Fig.1). After passing through the track membrane with the filtering efficiency not less than 99.0%, the air from a class 100 room satisfies class 1. Eight elementary blocks together have 50 m^2 of the track membrane (about 6 m^2 each). This figure, based on the optimised values for the pore diameter 0.8 μm (10% porosity) and pressure difference at the membrane 300 Pa, was chosen to ensure the output air flow velocity 0.5 m/s [7,8,12]. Fig.3 shows the general view of the block on the test bed.

Assembled under ordinary lab conditions, the prototype filters underwent two-stage washing with recirculative purification of the media (deionised water and ethyl alcohol) by means of a microfiltration membrane with 0.2 μm pores and then were dried in a laminar box with a class 100 air flow. The assembling implies a triple check applied to the roll membrane, the membrane in the filtering plate and the elementary block as a whole.

2. Local clean work place

The power consumption of traditional air supply systems for clean rooms and working zones directly depends on the hydrodynamic characteristic of the filters, i.e. with power consumption of ventilation devices for blowing the air and maintaining the air difference. The service life of the filters is limited because of constant dust load from outside (15-20% of the outside air must be constantly supplied to the room to maintain normal conditions for personnel activity).

We have proposed a power saving method of air supply to local clean work places [13-16]. This approach, which prevents penetration of microparticles and micro-organisms in the working zone and in the atmosphere, is based on the diffusion gas exchange of air components through the track membrane pores when there is no pressure difference. The intensity of this gas exchange is proportional to the partial pressure difference of components on both sides of the membrane that separates the clean volume from the outer air. The most favourable conditions for interdiffusion of gas molecules in pores are provided by blowing the air along both surfaces of the membrane with the pressure difference close to zero. Fig.4 schematically shows the organisation of a local clean work place.

In this case there is no need in excess air pressure inside the local work place, and the total power consumption is the power consumed by the internal dust-removing filter (clean benches, ordinary laminar boxes,etc.) and by low-power fans blowing the air along the membrane surfaces. It gives a minimum dust load on the internal filter, which is reduced to the general amount of microimpurities released into the working volume by the machinery and the personnel.

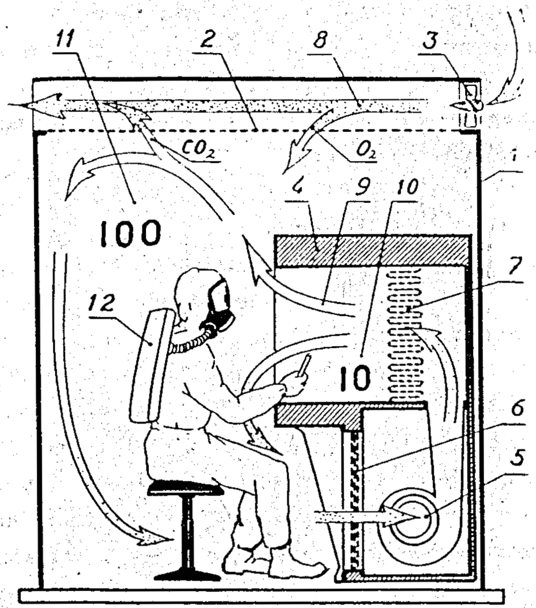


Fig.4. Layout of a local clean working place. 1 - working place chamber; 2 - track membrane; 3 - low-power fan producing a tangent air flow; 4 - dust removing box; 5 - fan of dust removing box; 6 - prefilter of dust removing box; 7 - final filter of dust removing box; 8 - flow of outside impure air; 9 - laminar flow of inside cleaned flow; 10 - working zone; 11 - "grey" zone of local working place; 12 - respirator (gas mask).

Fig.5. Local working place.

Fig.6. P[illegible]rking inside [illegible]lace (well seen is the ceiling with a track membrane).

Our investigations in an $8\ m^3$ local work place with a KL-21 laminar-flow dust-removing chamber, a $4\ m^2$ ceiling panel with track membranes and VN-2 low-power fans proved the efficiency of this organisation. Fig.5 is the general view of the local clean working volume, and Fig.6 shows the work of the personnel under extra clean conditions in this volume (important stages in assembling and checking the filtering plates with membranes). It was found experimentally that about $1.5\ m^2$ of the track membrane are enough to support the activity of one man, and the size of its pores may be reduced, if necessary, to 0.05 μm without any negative effect on the diffusion gas exchange [13-15]. Class 100, maintained by the KL-21 dust-removing chamber, is achieved 5 minutes after switching it on (without the personnel and operating machinery).

3. Gas exchanger

The purpose of the gas exchanger is almost the same as that of the ceiling panel in the local clean working volume. It supplies air to closed vessels and rooms and prevents penetration of microparticles and micro-organisms both inside and outside. Its successful operation depends on its proper use and air-tightness of the closed volume. Unlike the ceiling panel, however, the gas exchanger is smaller in size and can have a much larger membrane area, if necessary. Besides, in the gas exchanger the membrane is protected against accidental mechanical damage.

Structurally the gas exchanger is similar to the elementary block of the final air cleaning filter. The difference is that all four sides of the block are connected to the air lines to produce tangent cross flows along the membrane (Fig.7). The dimensions of the block depend on the dimensions of the filtering plates (280×280 mm). The plate thickness may vary from 2 to 2.5 mm. The working surface of a track membrane in a filtering plate is 500 cm^2. The air channel of neighbouring plate in the block are perpendicular to one another, so that the channels of one direction are united into one circuit, e.g. internal, and the channels of

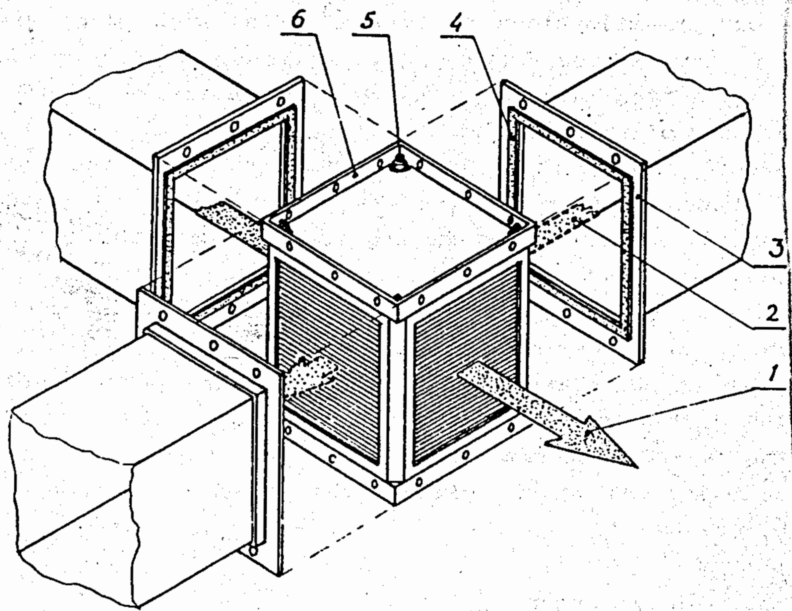


Fig.7. Connection of a gas exchanger. 1,2 - air flows in the inner and outer circuits; 3 - air line flange; 4 - sealing gasket, 5 - stud; 6 - metallic lid.

the other direction are united into another circuit, e.g. external (Fig.7). The maximum pressure difference amplitude on the membrane should not exceed 50 Pa. The hydraulic resistance of the block at the optimum air flow rate (for each circuit) of 250...350 m^3/h is about 50-60 Pa. This gas exchanger allows 1.3 m^3/h of oxygen, the difference of oxygen concentrations in the internal and external circuits being 1%.

The gas exchanger was tested in a hermetically sealed zone 3 m^3 in volume with 3 men working in it [14-16]. The scheme of connections is shown in Fig.8. A decrease in the pore size from several micrometres to 0.1 μm did not show worsening of the gas exchange. This fact proved experimentally that large variation of the pore size and porosity of a PET track membrane does not noticeably affect the intensity and dynamics of the diffusion gas exchange processes. No breakthrough of microparticles and micro-organisms was observed, except for an insignificant amount of

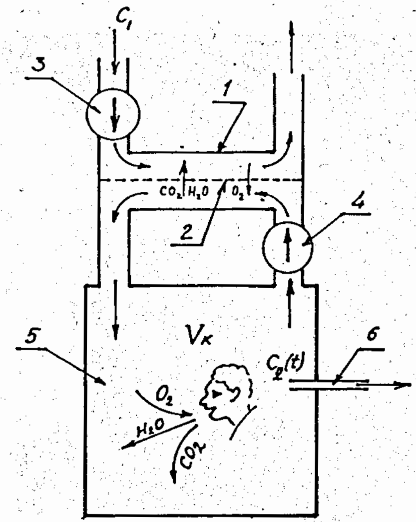


Fig.8. Connection of a gas exchanger to a clean working place (instead of a ceiling panel with track membranes). 1 - gas exchan- ger; 2 - track membrane; 3,4 - fans of outer and inner circuits; 5 - clean working place volume equal to V; 6 - sampling.

fine oil fog, which most probably results from condensation of oil vapour that penetrated through the diffusion gas exchanger.

4. Diffusion respirator

Another original modification of the gas exchanger is a diffusion respirator. Its operation is based on diffusion gas exchange through a track membrane 10 μm thick with pores from 0.03 to 0.5 μm in diameter and a mean porosity of 10% [17], see Fig.9.

Since human respiration is characterised with low air flow velocity (not more than 1 m/s), the diffusion rate of gas components depends on still near-wall air layers rather than on the track membrane thickness.

The operating model of the respirator consisted of a V-shaped breather bag (without a protective shell) and a rubber mask. The breather bag was connected to the mask with two flexible rubber pipes through the inhalation and exhalation valves. The diffusion respirator is schematically

Fig.9. Clean room operator with a diffusion respirator.

shown in Fig.10. The weight of the breather bag with the pipes was 58 g, the total surface of the bag was 2680 cm^2, the working surface of the membrane was 2100 cm^2.

The respirator showed the following performance in the tests:

- resistance to breathing when inhaling or exhaling - 15 Pa;
- resistance to breathing was the same for all the test time (60 hours of continuous work);
- dust entrapping efficiency for particles over 0.2 μm - 100% (the size of pores was 0.23 μm);
- operation was normal at the relative humidity up to 100%.

Comparison of this performance with the certified characteristics of ordinary antidust respirators showed that the diffusion respirator had indisputable advantages. Besides, the microbiological environment of human lungs is maintained in its breather bag, which is important for normal and healthy work, e.g. in extra clean rooms where the atmosphere is detrimental to the human immunity system.

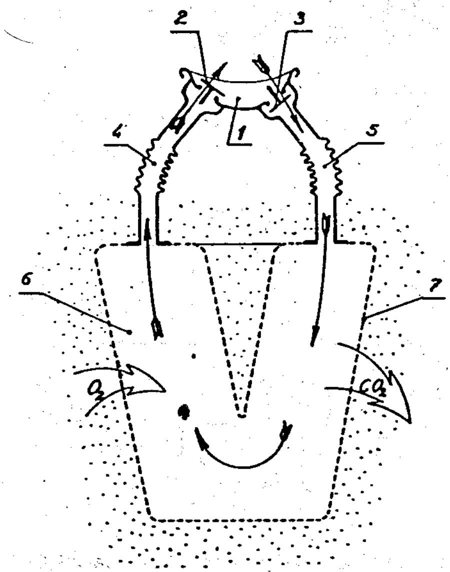


Fig.10. Schematic diagram of a diffusion respirator. 1 - front part (half-mask or full mask); 2 - inhalation valve; 3 - exhalation valve); 4 - flexible inhalation hose; 5 - flexible exhalation hose; 6 - breather bag; 7 - track membrane.

5. Biotechnological protection of a fermenter

The acute problems in biotechnology are known to be the protection of environment against penetration of cells and their fragments and protection of the nutrient medium in a fermenter against alien microflora during cultivation of micro-organisms.

A very simple solution was proposed [18]. Fig.11 shows a diagram of connection of a gas exchanger to a fermenter. The air is pumped through the medium with cultivated

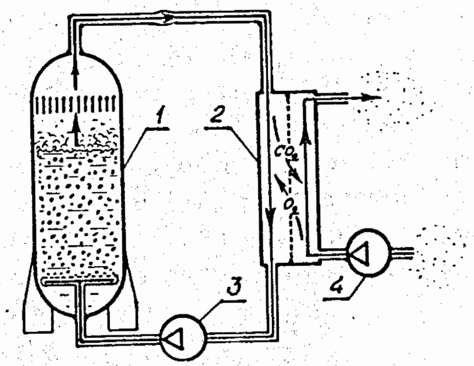


Fig.11. Technological scheme of gas exchanger connection to a fermenter. 1 - fermenter; 2 - gas exchanger; 3,4 - air compressors (fans).

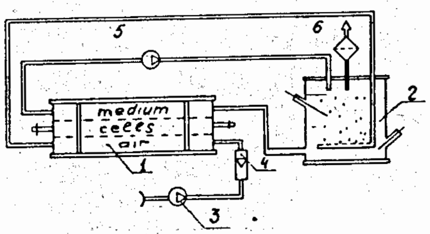


Fig.12. Connection of a membrane bioreactor. 1 - membrane bioreactor; 2 - nutrient medium reservoir; 3 - air compressor; 4 - rotameter; 5 - peristaltic pump; 6 - filter.

micro-organisms and along the track membrane surface where the exchange of air components (mainly CO_2 and O_2) takes place. If the cultivation process allows cell and their fragments back into the fermenter, the track membrane in the gas exchanger is a sure barrier for microflora in both directions.

This connection scheme was tested with a 10-litre depth fermenter where *Corinebacterium glutamicum* and *Saccharomyces cerevisiae* were cultured [14-16]. The experimental results showed that the oxygen and carbon dioxide gas exchange satisfies the cultivation with membranes having both 0.1 μm pores and 0.5 μm pores (two gas exchangers with different pore diameters). The fact that there was no breakthrough of cultured micro-organisms into the air and no contamination of the culture with alien microflora proves the reliability of this air supply scheme.

6. Membrane bioreactor

One of the most promising fields for using membrane systems in biotechnology is immobilization of cells and enzymes for biosynthesis and biocatalysis. We proposed a method for immobilization of micro-organisms with track membranes in a membrane bioreactor. The fact that micro-organisms are between membranes ensures diffusion of nutrients and oxygen to the cells, yield of the solution with the biosynthesis product, and prevents the cultured cells from leaving the bioreactor chamber. This immobilization allows free motion of cells inside the chamber and prevents their mechanical damage. This scheme is similar to the fermenter air supply scheme, but it involves both air and liquid substrate (Fig.12) [19,20].

The size of the track membrane pores was chosen with the help of calibration break-through curves for micro-organisms placed on the surface of a track membrane in Petri dishes [21]. The circulation regime for the nutrient medium in the membrane bioreactor was selected on the basis of the experimental results which allowed estimating the possibility of inactivation of enzymes secreted. The work involved microbic and mycelium cultures. It was shown that immobilization of micro-organism cultures in a membrane bioreactor with track membranes allows an increase in the general yield of enzymes secreted owing to a longer time of productive function of cells. It also allows a biosynthesis product cleaned of biomass.

Conclusion

Applications of track membranes to air supply and cultivation of micro-organisms are not reduced to the above development. Now the effect of electric and electrostatic fields on the aerosol separation efficiency is extensively studied, attempts to construct combined systems for gas exchange and entrapping of aggressive components are made, and so on. Yet, all these approaches to a solution of a problem have one feature in common, which is the use of specific or sometimes unique properties of a track membrane traditionally made of a PET film.

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