A TRANSPORTING AND A DEFLECTION OF THERMAL NEUTRONS USING POLYVINYL CHLORIDE TUBES COATED WITH FLUORINE POLYMER

S. Arzumanov, N. Miron, V. Morozov, Yu. Panin, A. Strepetov

NRC "Kurchatov Instute", 1, Akademika Kurchatova sqr., Moscow, Russia, R-123182

Abstract

The possibility of transportation, deviation and optimization beams of thermal neutrons using flexible polyvinyl chloride (PVC) tubes with internal fluorine polymer coating is shown. Experimental results on transportation of thermal neutrons using the straight and bent tubes are presented.

As shown in [1, 2], PVC $(CH_2\text{-}CHCl)_n$ tubes possess high reflectivity of the inner surface, but ones have low boundary velocity, which equal 2.8 m/s. However, when the inner surface is covered with liquid fluorine polymer «Fomblin YL VAC 18/8» the reflectivity of tubes increases. The boundary velocity V_{lim} of Fomblin is 4.56 m/s at that a probability of neutron losses per one collision with wall is equal $3{\cdot}10^{-5}$. Neutrons can be transported through such tubes by reflections from walls, if their normal to the walls component of the velocity $V_n<V_{lim}$.

Such tubes can be used for transportation, deviation and formation of thermal neutron beams at research nuclear reactors.

Figure 1 shows a measuring scheme of transmission probability of thermal neutrons through a tube length L = 140 cm and with an inner diameter of 8 mm. Outer diameter of the tube was14 mm. The thermal neutron beam of reactor IR-8 (NRC "Kurchatov Instute") was used for measurement. The relative share of epithermal neutrons with energy higher than 0.4 eV in the beam was 0.3 and average velocity of neutrons was 4400 m/s. The neutron beam was formed with the help of steel collimator with an inner diameter of 20 mm and length of 1 m, as well as of outlet collimator of boron polyethylene with an inner diameter of 8 mm and length of 11 cm. The input end of the tube was installed to the outlet collimator. The neutron flow that passed through the tube was registered with using ^{3}He gas proportional detector. The thickness of the detector gas layer was 5 cm, the composition of the gas mixture is ^{3}He – 60 mbar, Ar – 1 bar, CO_2 – 25 mbar. The outlet end of the tube was supplied to the detector through the hole in the boron polyethylene shield.

The transmission coefficient of the tube $W(X)=\frac{I(X)}{I(0)}$ was measured in the experiment. There $I(X)$ is a count rate of the detector when the deviation of the tube output on distance X from the direction of the reactor beam axis, $I(0)$ is a count rate of the detector at the output of a straight tube (Fig. 2). At smooth deviation of the tube detector moved together with its output end.

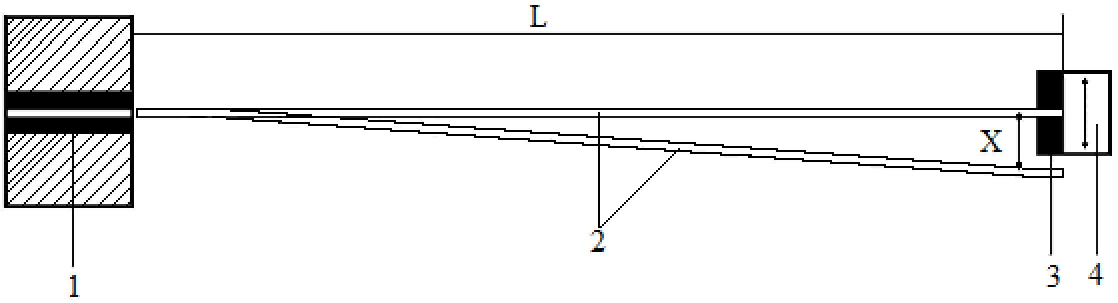

Fig. 1. Scheme of the experiment on the measurement of the transmission of neutrons by a tube. 1 – collimator of neutron flux; 2 – tube, 3 – detector's shield; 4 – neutron detector.

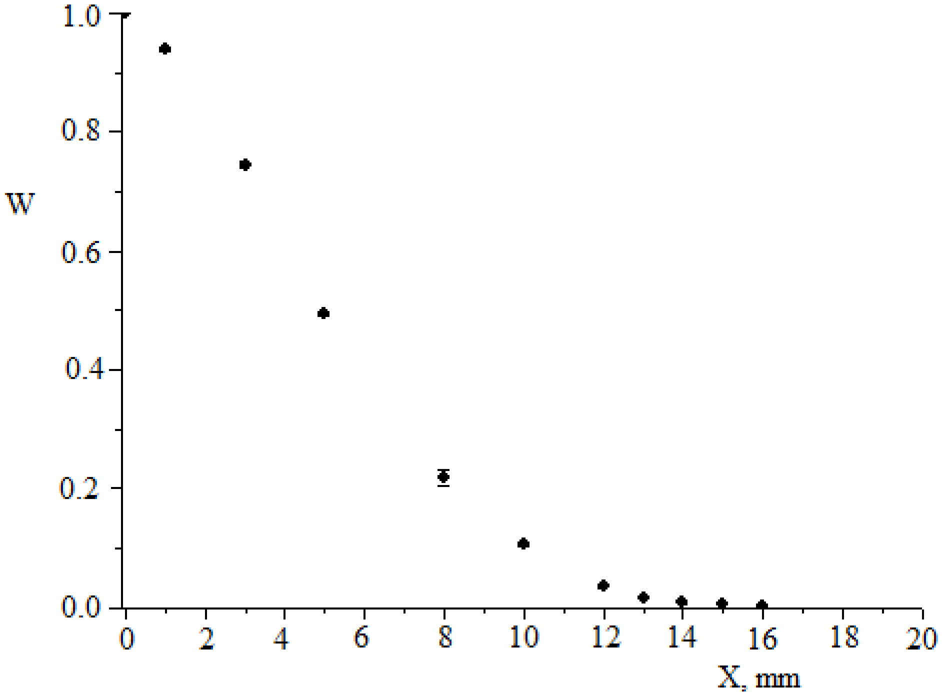

Fig.2. Transmission coefficient *W* versus the deviation *X* of output end of tube.

It follows from fig. 2 that at the deviation of the tube output end of *X* = 8 mm (one diameter) output neutron flux is 0.22 from output neutron flux of a straight tube. At the deviation of *X* = 16 mm (two diameters) the intensity is reduced to 0.03 from output intensity of a straight tube. It should be noted that the deviation of the outlet tube of 1 diameter already allows to move out the neutron beam from a zone of hard reactor gamma radiation saving the output intensity of neutron flux at the level of 20 %

To reduce the upper boundary of neutron velocity to the reactor beam was introduced Bragg's filter, made of microcrystalline diamond. Filter with length of 40 cm allowed to lead out through the collimator neutrons with upper boundary velocity of 950 m/s. At this beam, the transmission of the neutrons through straight tube with fluorine polymer coatingwas investigated.

For measurements of the input and output, neutron flux was used position-sensitive neutron detector Imaging Plate with thin film of gadolinium. The detector allowed to getneutron image of the beam in the plane perpendicular to its axis. The scheme of formation of the neutron beam in different geometries of the experiment and obtained neutron images is shown in Fig. 3.

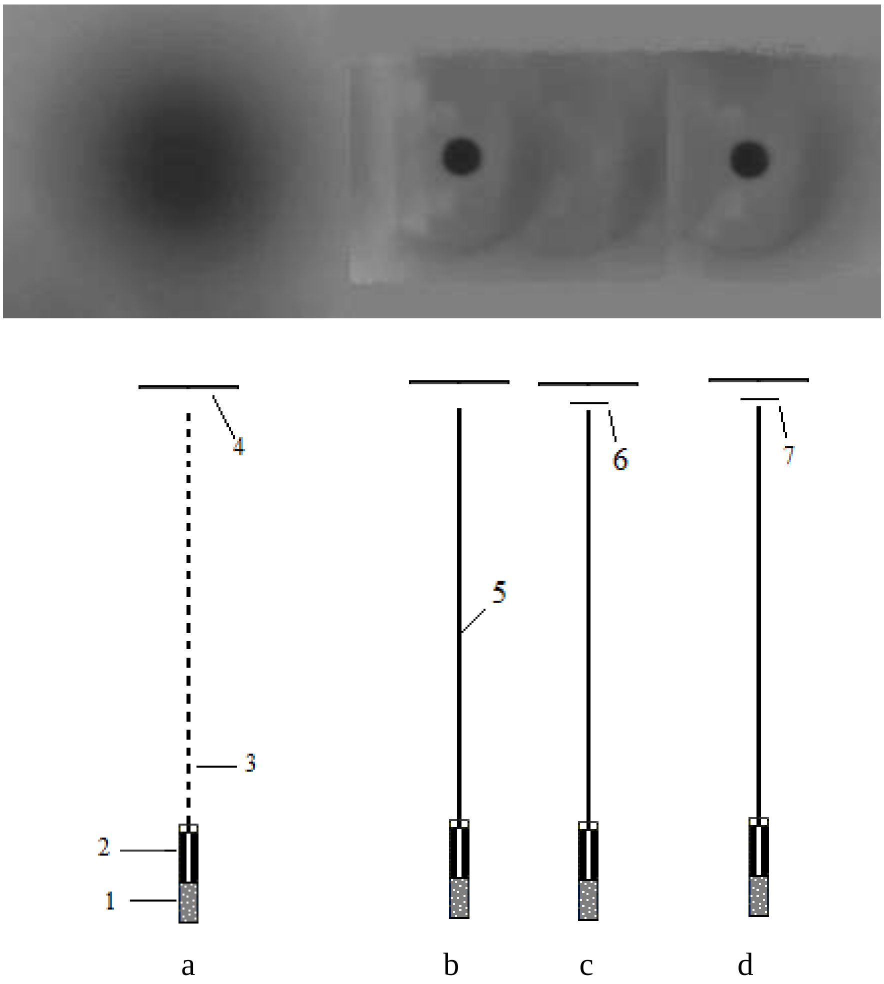

Fig. 3. The scheme of the transmission measurement of neutrons through straight PVC tube and obtained neutron-optical image on the Imaging Plate (upper). 1– diamond filter; 2 – collimator of boron polyethylene; 3 – axis of the neutron beam; 4 – Imaging Plate; 5 – PVC tube; 6 – cadmium screen; 7 – molybdenum screen.

In the experiment without the tube (Fig. 3a) the image is a spot with full width at half maximum of (30–35) mm. The size of the beam in the plane of Imaging Plate screen is determined by the size of collimator hole and angular divergence of the beam.

The second exposition (Fig. 3b) is made with a tube, installed along of the beam axis. The image is a spot with diameter of (8–9) mm. Spot size is close to the inner diameter of the tube. The image formed by neutrons that passed the tube directly as well as reflected from the walls, when their normal component of the velocity $V_n<V_{lim}$ for fluorine polymer coating.

The third exposition (Fig. 3c) is made with cadmium screen of 0.5 mm thickness installed on the outlet of the tube. In this case, no picture, this shows that the image (Fig. 3b) is caused by thermal neutrons, which in this exposition are fully absorbed in cadmium.

The fourth exposition (Fig. 3d) is made when instead of cadmium screen on output of the tube was installed molybdenum screen of 0.6 mm thickness. Molybdenum has capture cross-section of neutrons by three orders of magnitude less than cadmium but provides the same absorption of soft gamma radiation as with the cadmium screen. It is seen that soft gamma radiation coming from a reactor through collimator on Imaging Plate is almost imperceptible.

The image on the detector registration plate consists from pixels of 0.2×0.2 mm^2. Each pixel can be attributed to 32000 grayscale color (range from white to black), at that each gradation proportional to the density of neutron flux. Fig. 4 presents the distribution of the neutron flux density *J* in the detector's plane along the horizontal axis passing through the center of each spot.

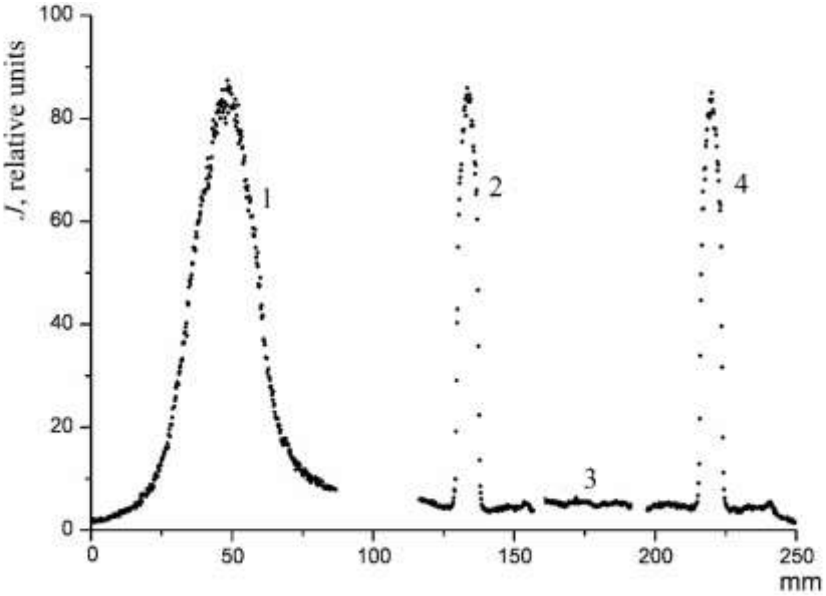

Fig.4. The distribution of neutron flux density in the plane of the detector Imaging Plate along the horizontal axis. 1– without the tube; 2, 3, 4 – with the tube; 3 – at the outlet of tube screen of Cd; 4 – at the outlet of tube screen of Mo. On the X-axis indicate the coordinates of the pixels without absolute binding.

Fig. 5 presents the scheme of the experiment on the deviation of the neutron beam by using flexible PVC tube with fluorine polymer coating. The tube had a length of 110 mm and inner diameter of 8 mm. Input end of the tubewas set into the collimator of boron polyethylene installed after diamond Bragg's filter. Position-sensitive detector (Imaging Plate) registered neutrons that passed through the tube. For deviation from the axis of the reactor, beam tube was smoothly bentat the initial section of (20–70) mm length. The rest of the tube was straight. At the same time, the output end of the tube deviated from the beam axis at a distance *X*.

The neutron-optical images of the beam coming out of the tube at a deviation its outputstraight upto a distance *X*are presented in Fig. 6. Images obtained on one plate at its successive offset by (20–25) mm for every new deviation *X*. Maximum deviation of the output tubes is X = 31mm.

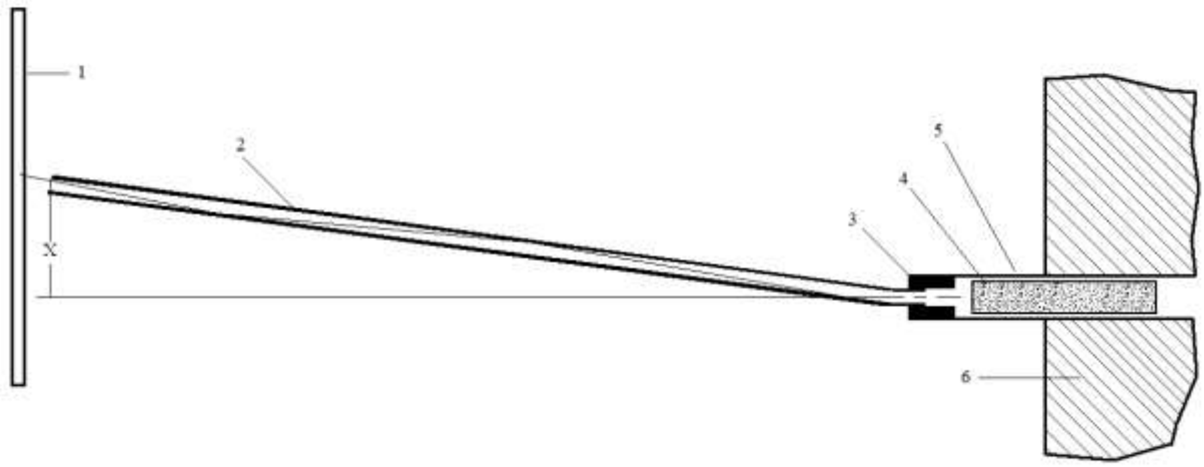

Fig. 5. Scheme of the experiment on the deviation bytube of the thermal neutron beam. 1 – plate of position-sensitive detector; 2 – PVC tube; 3 – collimator of boron polyethylene; 4 – neutron filter from diamond micro-powder; 5 – steel output collimator of horizontal experimental channel 7a; 6 – reactor protection.

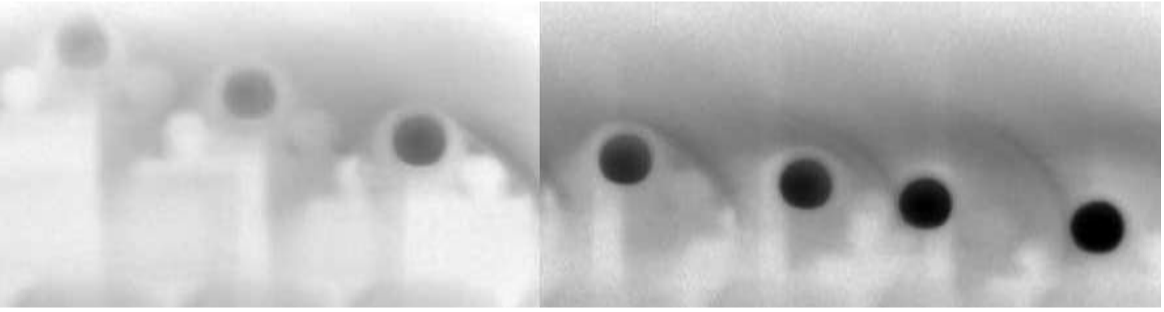

Fig. 6. The neutron-optical images of the beam coming out of the tube at a deviation its output straight up to a distance *X*.

Fig. 7 presents the dependence of the transmission coefficient of full neutron flux by a tube versus the deviation*X*. It is visible, that with the help of a tube reactor neutron beam is deviated by reflections part of neutrons from internal fluorine polymercoating. At that, the spectrum of neutrons output flux is softened. When the deviation is one diameter (X = 8 mm), coming out of the tube neutron flux is 0.52 from out-flux of the straight tube. Even if the deviation is 2.5 cm (more than 3 diameter) neutron flux from the tube remains at level of 10%.

The measurements have shown that PVC tubes with internal fluorine polymer coating can be useful for a number of neutron - physical research:

- forming of the necessary spectrum of the output neutron flux using the method of tubes bending;
- focusing of neutron beams with the help of tubesfor the purpose of increasing local density of neutron flux;
- carrying out of neutron radiation analysis on large samples using deflection of thermal neutrons beams;

- studies of the pharmacokinetics of boron-10 isotope in animals and humans toneutron reactor beams, which deflected from field of intense gamma-ray radiation;
- the direct use of tubes in neutron capture therapy of cancer; tubes can be used for irradiation of malignant tumor todeflected neutron beams without damaging of healthy tissues as a resultof reactor gamma radiationimpact. When used cold neutrons for the therapy [3] it is possible useflexible tubes as medical catheters for direct delivery of neutrons to malignancy.

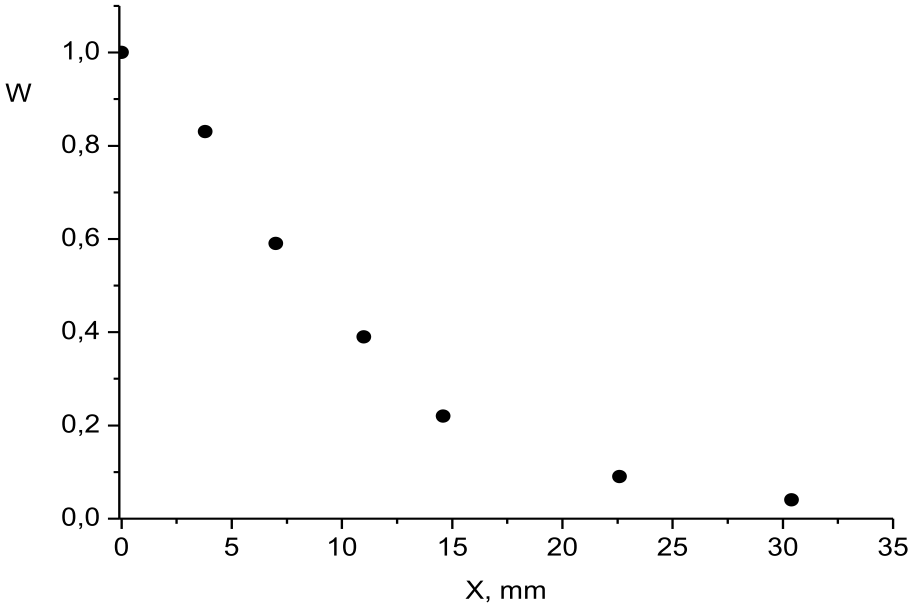

Fig. 7. The dependence of the transmission coefficient of the tube from the deviation value *X* of tube output end.

References

1. S.S. Arzumanov, L.N. Bondarenko, P. Geltenbort et al. Flexible Polyvinyl Cloride Neutron Guides for Transporting Ultracold and Very Cold Neutrons // Crys. Rep. 2011, v.56, No. 7, pp. 1197-1199.
2. S. Arzumanov, L. Bondarenko, S. Chernyavsky et al. Flexible Polyvinyl Cloride Tubes to Transport Low Energy Neutrons and Some Options for their Application // Proc. of the 20 Inter. Seminar on Interaction of Neutrons with Nuclei. Dubna, 2013, pp. 39-43.
3. S.S. Arzumanov, L.N. Bondarenko, P. Geltenbort et al. Физические особенности и перспективы использования ультрахолодных и очень холодных нейтронов в нейтрон-захватной терапии. Препринт ИАЭ-6649/2, Москва-2010, 23 с (in Russian).