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PULSED AND QUASISTATIONARY NEUTRON SOURCES BASED ON PROTON BEAMS OF MOSCOW MESON FACTORY

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The authors describe an assembly of neutron sources for physical research based on proton beams of the Moscow meson factory. The expected neutron intensity in the 4π solid angle in the regime of the resonance selector is $3*10^{16}$ *n/s (25 ns, 400 Hz) while the peak density of the thermal neutron flux on the illuminating surface of the moderator is ≃* $5*10^{15}$ $n*cm^{-2}*s^{-1}$ *and the pulse duration is ≃ 50 μs.*

The Meson fasility of the Institute for Nuclear Research of the Soviet Academy of Sciences, which is under construction in Troitsk, is the high current accelerator of protons and H^- ions for energies of 0.6 GeV at the current of 0.5-1.0 mA. Intensive beams of protons, also including polarised protons, beams of π, μ - mesons and neutrinos resulted from the proton interactions with the matter of meson targets and beam stops give the possibility to develop the research in various fields of physics, from fundamental problems of matter structure /1/ to the study of radiation damage of materials /2,3/.

Intermediate energy protons allow intensive neutron fluxes to be obtained. Really, a proton with the energy of 0.6 GeV interacting with heavy nuclei [tungsten, lead] results in the release of 10-12 neutrons, more than 90% of which is "evaporated" neutrons with the energies of 2-3 MeV. In the case of ^{238}U target the number of secondary neutrons is about 20. Approximately the half of these neutrons are fission ones.

With proton beams available now average neutron fluxes are lower than those in experimental reactors. However, the possibility to change in the wide range the time structure of the proton beam and, correspondingly, the time structure of the neutron flux leads to unique experimental possibilities /4/.

The shaping of the short pulses of intermediate energy protons is based on the use of the stripping injection of H^- ions into the storage rings. The stripping injection proposed by Alvarez /5/ and carried out by Budker with co-workers /6/ gives the possibility to store in circular magnet assemblies the high circular currents of protons. One-turn extraction of protons from the storage ring of Moscow meson factory (Fig. 1) onto the external target gives the possibility to obtain the neutron pulses with the duration of 5-300 ns and the neutron intensity of up to $6*10^{16}$ n/s in the 4π solid angle.

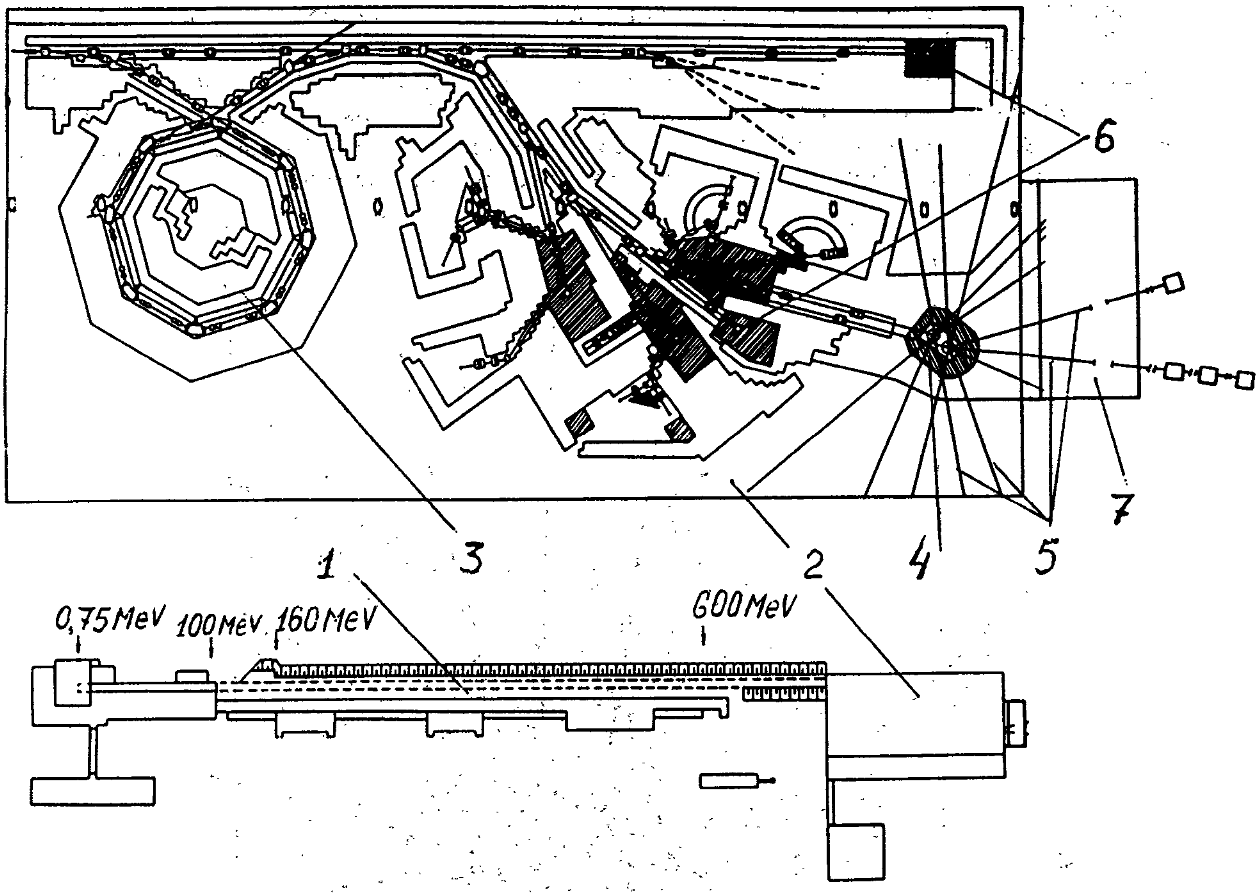

Fig.1. Moscow meson factory; 1-linear proton accelerator: 2-experimental hall; 3-proton storage ring; 4-assembly of neutron sources; 5-neutron guides; 6-beam stops; 7-neutron laboratory.

On the basis of the bunched proton beam the pulsed neutron fluxes of thermal and cold neutrons for researches on condensed matter physics as well as the fluxes of resonance neutrons may be obtained. Spectrometers of resonance neutrons based on the pulsed neutron source of Moscow meson factory will give a possibility to carry out research on the neutron nuclear physics, to study in details the partial processes of the neutron interactions with nuclei in isolated resonances and in the field of the overlapping levels.

The pulsed character of the primary neutron flux, when the neutron release between pulses is small [this release for ^{238}U ~ 1%, for lead ~0.1%, and for targets of a medium atomic weights, for example molibdenum targets, ~10^{-5}% /4/], gives the possibility to obtain in good moderators (D_2O, Be, C), if the time selection of events is used, the quasistationary fluxes of thermal and cold neutrons with the small additions of over-thermal and fast neutrons (time thermal "column"). Time selection of the background allows such experiments as the study of neutron-neutron scattering and the search of neutron-antineutron oscillations to be implemented /7/.

The assembly of neutron sources is constructed on the basis of two proton beams, which can be used simultaneously. The first one is the proton beam from the accelerator with the average current of up to 1 mA. The time structure of the beam is the sequence of macropulses with the duration ~100 µs. The repetition rate is up to 100 Hz. This beam hits onto the neutron target of the quasistationary source of thermal and cold neutrons (Figs. 2, 3, 5). The second beam bunched in the storage ring with the stripper injection and the one-turn extraction and having the form of the pulse sequence with the duration of 5 - 300 ns and the repetition rate of up to 400 Hz at the average current of up to 500 µA hits at the neutron source (Figs. 2, 3, 6). In the assembly of neutron sources there are also the proton beam stops with vertical canals to carry out experiments on radiation physics /2, 3, 9/ and to obtain neutron deficient radionuclides. The beam dumps operation is defined mainly by the programme of experiments on meson beams.

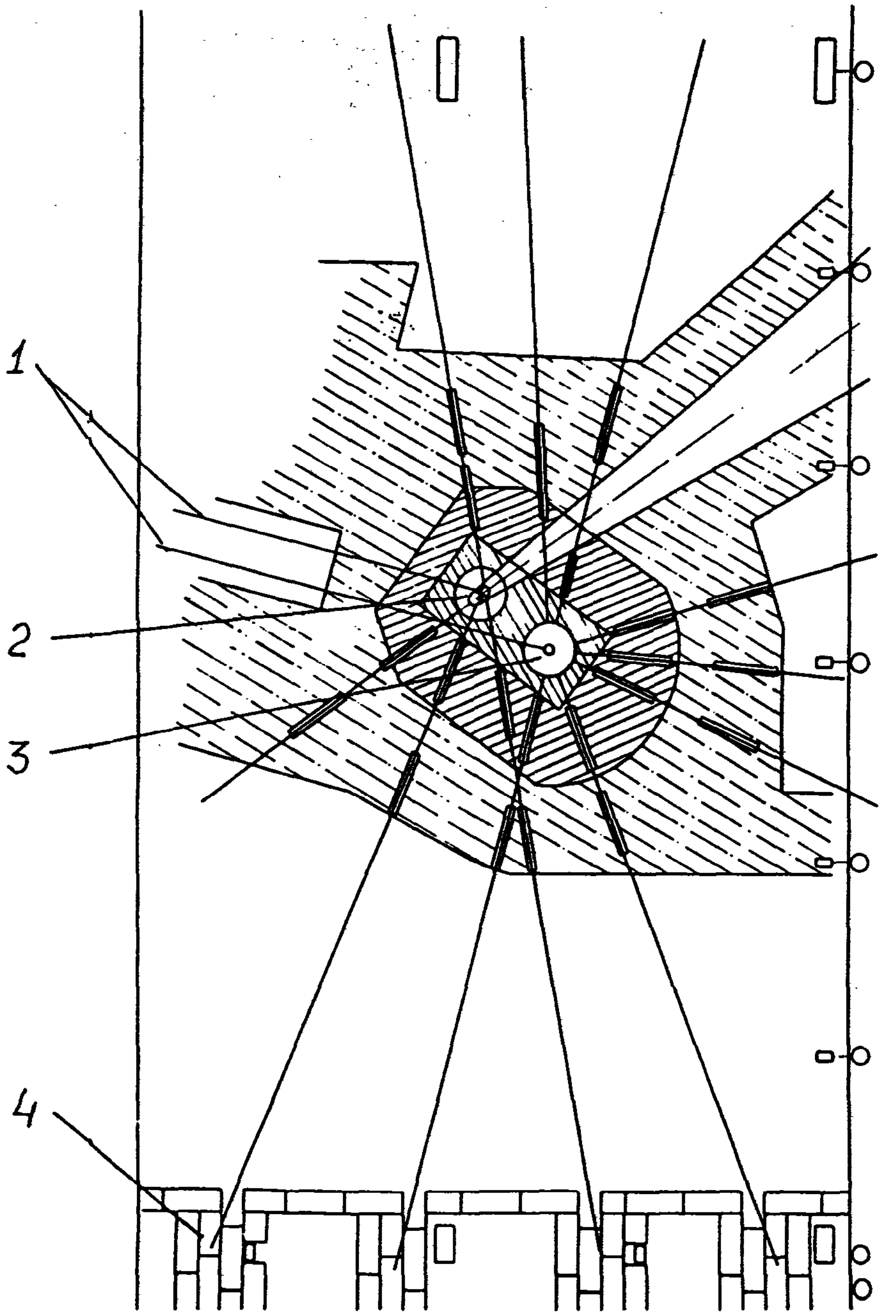

Fig.2. Assembly of neutron sources: 1-proton beams; 2-quasistationary source of thermal and cold neutron; 3-pulsed neutron source; 4-neutron beam stop.

The principal construction scheme of the neutron sources and beam stops consists of the three main parts: 1) tank with the vacuum bend, 2) ampoule with water-cooled target, 3) remote-controlled vacuum seal. By means of the vacuum bend the ampoule with the target [beam stop] is placed into the proton beam. The "first wall" dividing the vacuum set and coolant is the ampule wall made of the aluminium alloy. Vacuum seal is in the field of low neutron fluxes and made of the rubber. Such arrangement allows rapid change of target devices to be carried out. Remote-controlled vacuum seal consisting of two coaxial bellows the space between which is filled by the gas under pressure, allows the disassembly of the whole source to be carried out. If such need arises the placing of the beam pichups, scrapers, additional windows is also possible. The main dimensions of the target ampoules and beam stops is unified. So, the construction scheme is rather flexible, interchangeable and allows the further development.

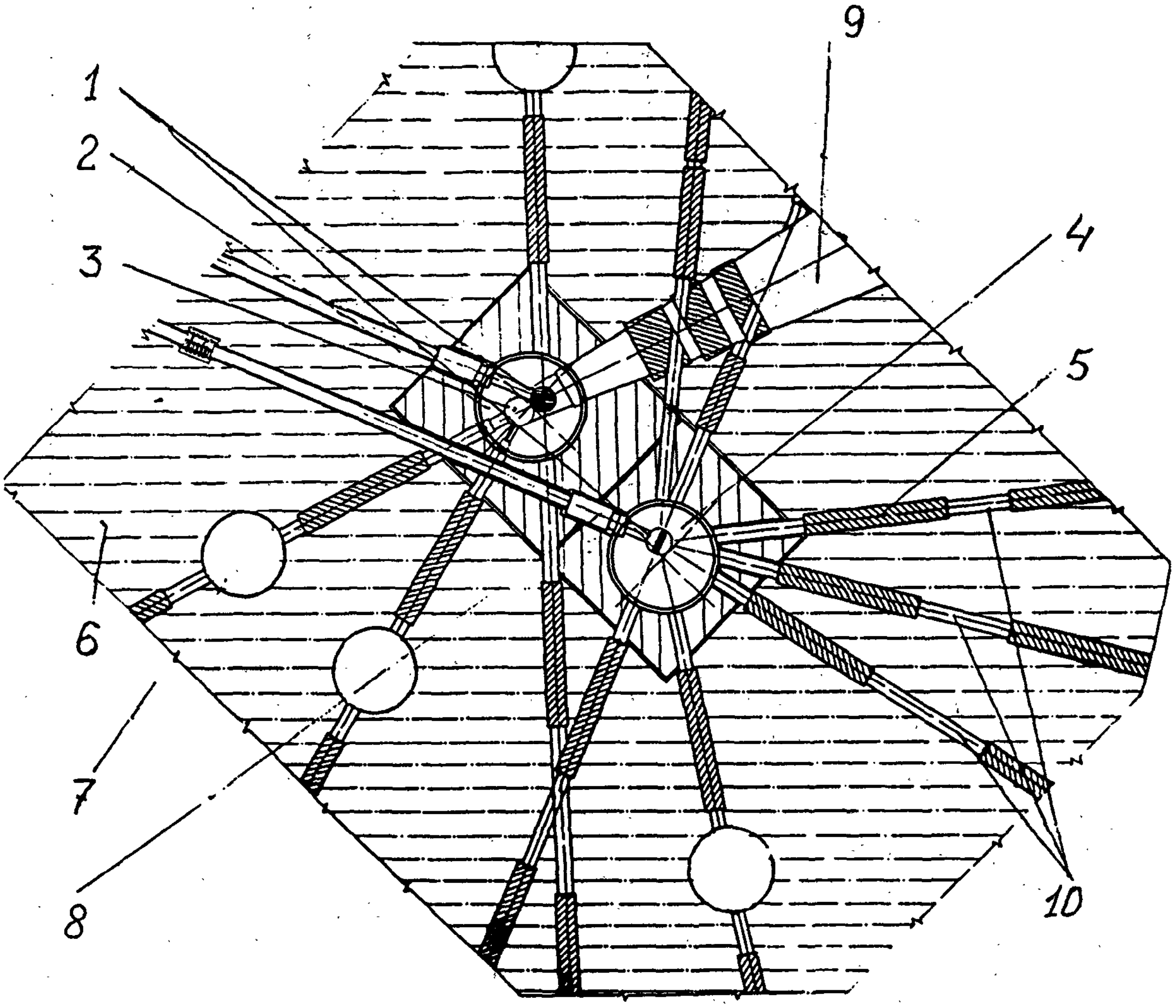

Fig.3. Assembly of neutron sources, central part: 1-neutron targets; 2-heavy water tank; 3-liquid deiterium moderator; 4-vacuum tank; 5-shut-off gate; 6-heavy concrete; 7-vertical wells of the diameter 1 m; 8-remote-controlled vacuum seal; 9-wide apperture canal; 10-canals of resonance neutrons.

Both sources are in the cylindrical boxes of the radiation protection made of steel and concrete and are looked out through the set of the canals with the shutter of the "guillotine" type.

For the placing of additional experimental equipment neutron canals have the vertical wells of 1 m diameter with the protecting valves /10/ on the distance of 3.5 - 4.0 m from the source.

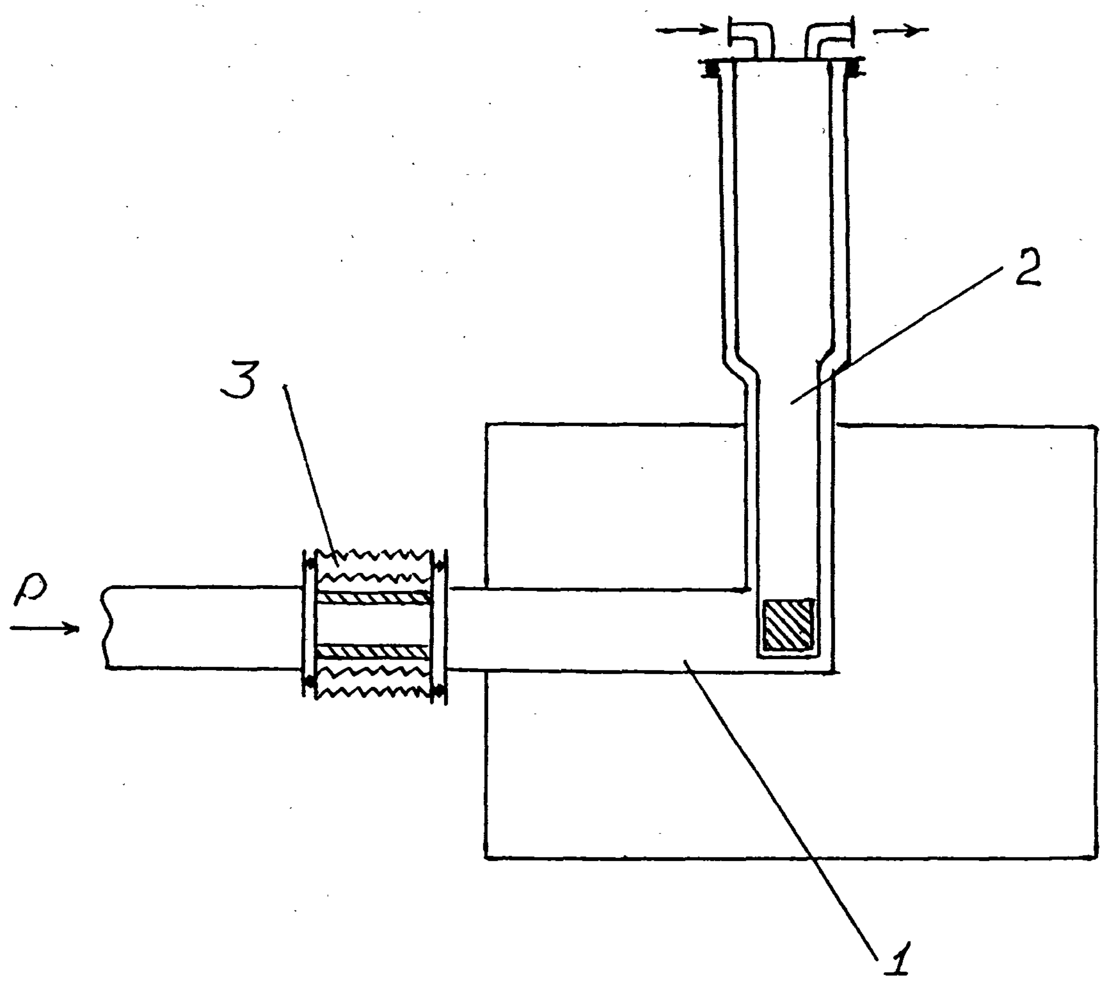

Fig.4. Design of neutron sources and proton beam dump: 1-tank with vacuum system; 2-ampoule of neutron source or beam dump; 3-remote-controlled vacuuum seal.

The quasistationary source of thermal and cold neutrons (Fig.5) consists of the water-cooled neutron target in the form of the closed package of rods made of natural uranium in stainless steel cans, heavy water moderator in the aluminium tank of 1.5 m diameter, liquid deuterium moderator of the volume ~20 l. On the first stage of the operation tungsten plates are supposed to be used. The liquid deuterium moderator radiates into the wide apperture canal for the experiments on the detection of neutron-antineutron oscillations as well as into the canals for the research with cold neutrons. With the removal of the liquid moderator the through tangential canal forms. This canal can be used for the experiment on the direct measuring of the length of neutron-neutron scattering and other researches in intensive fields of thermal neutrons /11/.

At the proton current of 0.5 mA the calculated value of the thermal neutron flux on the bottom of the experimental canal is about $3*10^{13}$ n/cm^{2}*s, the cold neutron flux [E < 5 meV] on the radiating surface of the cold moderator is of the order of 10^{13}

n/cm^2*s, with the effective neutron temperature being equal to 40° K. The radiating surface of the cold moderator is about 1000 cm^2. When ^{238}U is used and proton current ~0.5 mA the heat generation in the neutron target is of the order of 1 MW, in the heavy water 40 kW, in the cold moderator ~ 0.5 kW.

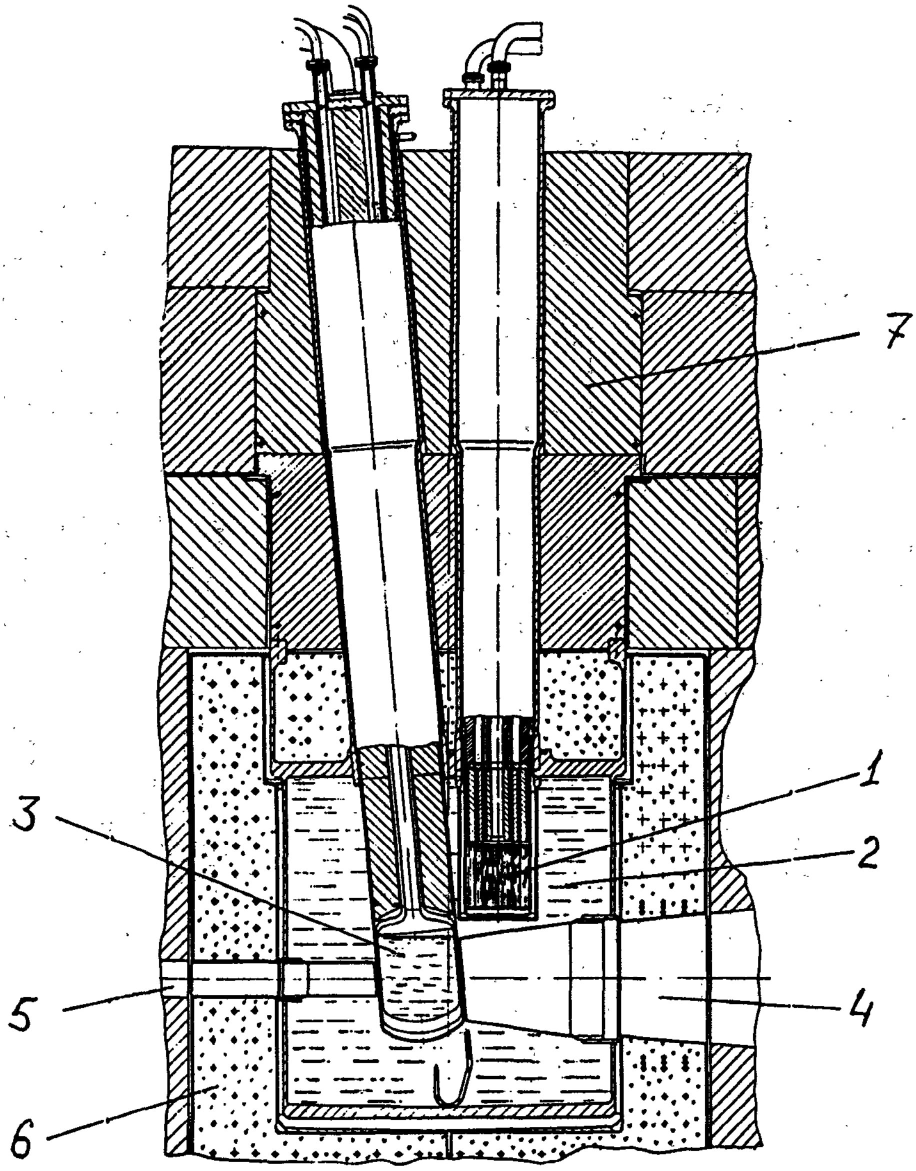

Fig.5. Quasistationary source of thermal and cold neutrons: 1-neutron target; 2-liquid deuterium moderator; 3-heavy water moderator; 4-canals for n-ν experiment; 5-extension of wide apperture canal; 6-thermal shield; 7-removable steel plugs.

The heat released in the heavy water is removed in external heat exchanger. The liquid deuterium moderator is cooled by means of the deuterium vapour condensation in the heat exchanger blown on by the helium at temperature 15•K from the refrigerator.

The pulsed neutron source consists of the target assembled from the uranium rods [tungsten plates] and cooled by water and the set of moderators (Fig. 6). The moderators are adjoined to the upper and lower surfaces of the target. To decrease the background of scattered neutrons and prevent a pulse delay in the case of the operation with resonance neutrons both the target and moderators are placed in to the vacuum tank. Thin [~ 2 cm] light water moderator is looked out through the neutron canals for resonance neutrons with the flight distances of up to 500 m. The canals get out of the hall of the experimental complex (Fig.1). Neutron canals have intermediate pavilions. Above the target there are replaceable moderators for the work with thermal and cold neutrons. The use of

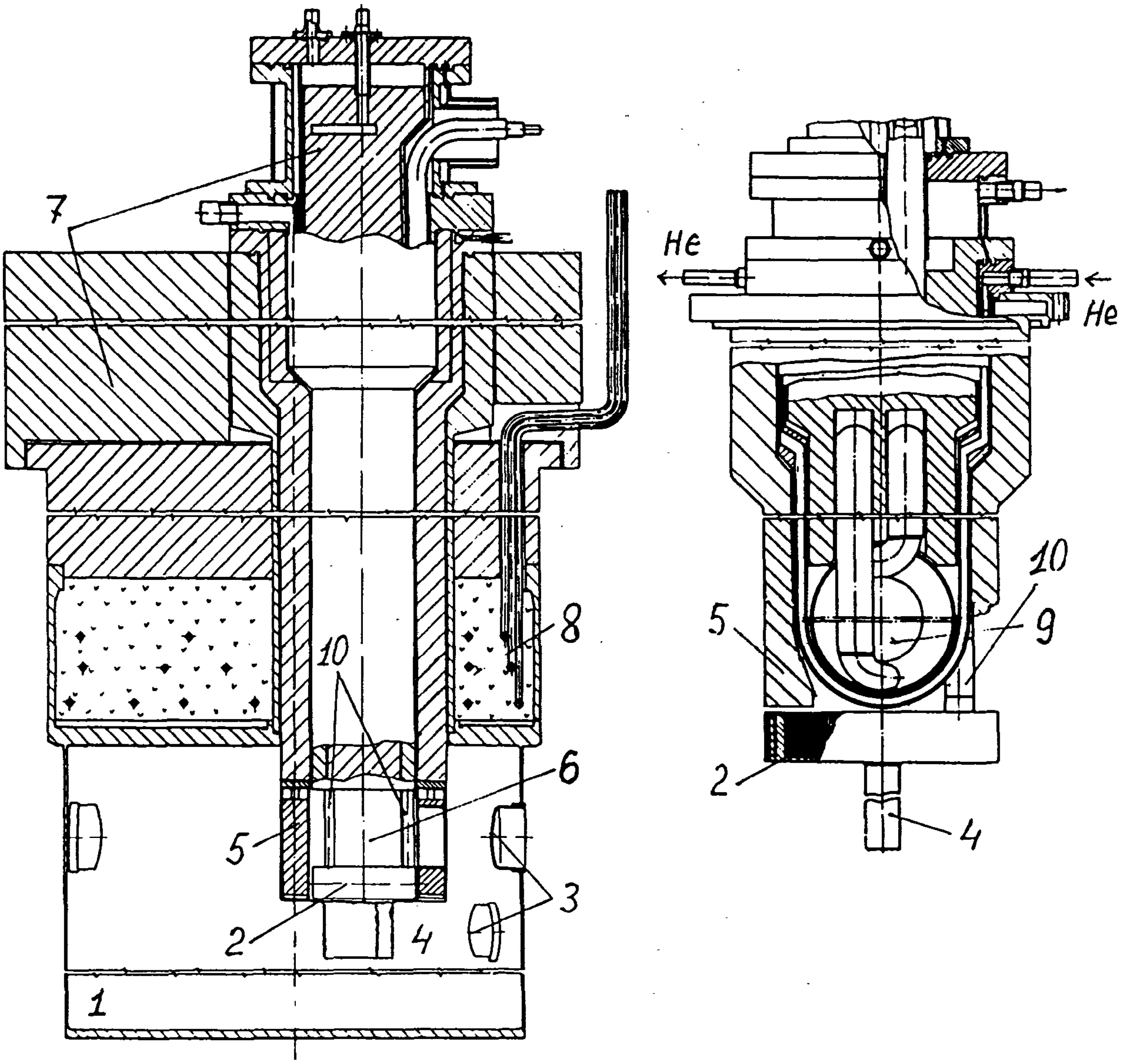

Fig.6. Pulsed neutron source: 1-vacuum tank; 2-assembly of rods made of uranium - 238 (or tungsten); 3-thin aluminum windows; 4-lower water moderator with thickness 3 cm; 5-reflector of upper moderator 6-place for the upper water or liquid-hydrogen moderator; 7-upper part of the thermal shield; 8-removable upper steel plug; 9-liquid- hydrogen moderator; 10-coolant's communications.

either the light water moderator of the thickness ~ 4 cm or the liquid deuterium moderator is supposed. These moderators have the Be reflector of the thickness 15 cm. Corresponding neutron canals look out to the experimental hall.

The peak density of thermal neutron flux averaged over the radiating surface of the water moderator [surface area ~400 cm^2] will be about $2*10^{15}$ n/cm^2*s when pulse duration ~50 µs.

In the presence of the reflector peak fluxes of thermal neutrons will reach the value of $5*10^{15}$ n/cm^2*s on the radiating surface area ~100 cm^2.

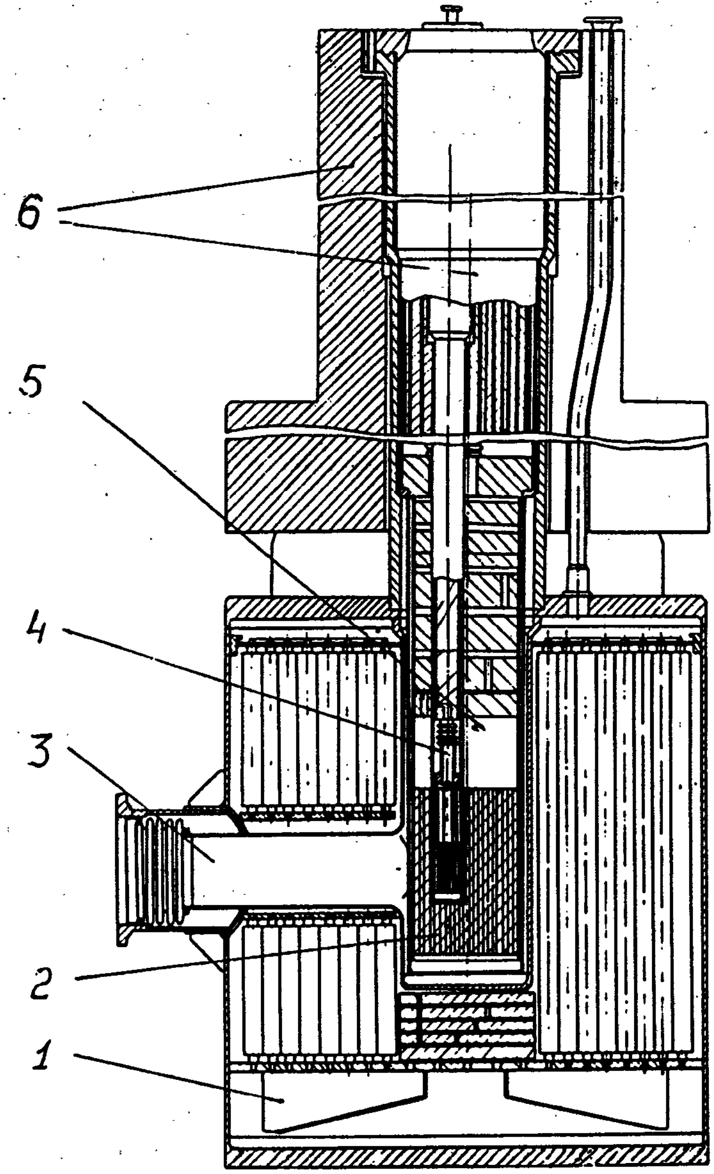

Fig.7. Proton beam dump: 1-thermal shield; 2-tungsten plates; 3-ion guide; 4-canal for sample irradiation; 5-ampoule of proton beam dump; 6-removable steel plugs.

The peak density of cold neutron flux on the surface of the cold moderator is ~10^{15} n/cm^2*s while the duration ~120 µs.

On the first stage of the neutron source operation tungsten targets will be used. In this case the average intensity and density of thermal and cold neutron flux will be approximately two times as less as compared to those in the case of the targets based on ^{238}U.

The works on further development of the assembly and improvement in performance are carried out now. In particular, the possibility to use multiplicating target with the limited multiplication [up to 20] is under consideration. This will allow the pulsed neutron source intensity to be increased by 5 - 6 times in the frequency range of 10 - 30 Hz, which is most convenient to carry out most experiments with thermal neutrons.

The provided possibility to change targets and moderators will allow the optimum conditions for every group of experiments to be chosen. So, in the biological shield there are stores for the replaceable target devices and other experimental equipment.

Proton beam stops are behind the meson targets in the assembled shield made of concrete and cast iron. The target core is the assembly of water cooled tungsten plates. The core is surrounded by the iron-water thermal protection. The vertical canal of the diameter 60 cm with autonomous water cooling allows irradiated samples to be carried into the target core (Fig.7).

Average proton energy in the canal is about 450 MeV. Average flux of fast neutrons in the canal will be $2*10^{14}$ n/cm^2*s at the current 0.5 mA.

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Q(P.A.Egelstaff): When the liq. D_2 moderator is in front of the target, many of the neutrons from the H_2O coolant will scatter directly from the D_2O down the beam tube. But if the liq. D_2 is placed in the position indicated by Dr. Bauer many neutrons from the H_2O coolant will pass through the D_2O from behind. Does this difference change the cold neutron flux seen in these two cases?

A(S.F.Sidorkin): In the case proposed by us the cold neutron flux is not less than in the other one; neutron losses due to a big hole was taken into account at optimization study.