PULSED NEUTRON SOURCE OF MOSCOW MESON FACTORY

Grachev M I, Kravchuk L V, Kuzin A V, Lebedev S G, Lobashev V M,
Miroshnichenko V G, Matveev V A, Ponomarev O V, Sazanov V N,
Senichev Yu V, Sidorkin S F, Sobolevsky N M
Stavissky Yu Ya.

Institute for Nuclear Research, Russian Academy of Sciences
Moscow

The Pulsed Neutron Source of Moscow Meson Factory is intended for investigations in the field of particle physics, of nucleus structure and mechanism of nuclear reactions, solid state physics in the range of neutron energies from thermal (cold) up to several MeV using the time-of-flight technique.

The neutron emitting occurs on heavy nuclei due to spallation process caused by bombardment of the target with 600 MeV protons from linac. On the primary stage for shaping of the proton pulses, and respectively neutron pulses of needed duration, proton beam chopping after the injector will be used, and later the proton storage ring with the charge-exchange injection will be used in the one-turn extraction mode. The scheme of the neutron source is presented on Fig. 1.

The neutron targets with the reflectors and the system of moderators are placed in two boxes of radiation shield made of iron and heavy concrete.

The shield is supplied with the channels, with shutters for transporting the neutron beams out (Figs 2, 3). The 1st circuit of the water cooling system for targets of heat power up to 2.5 MW (pumps, heat exchangers, ion exchange filters) is placed inside the concrete shield.

The placement of the neutron source in the experimental hall is shown on Fig. 4.

Neutron targets are settled in vessels made of aluminium-magnium alloy that are inserted into vertical channels of the proton beam vacuum system, the wall of the vessel serves as a 'window' of the target that separates accelerator vacuum system from the target coolant. The rubber-based vacuum sealing is placed in the box with the intermediate shield that provides the possibility of maintenance and fast change of the target together with the system of moderators when the proton beam is shut off.

The monitoring of proton beam distribution on the surface of the window is carried out by means of multiwire detector inserted in vertical channel in front of the target window.

The whole target system including the vacuum volume of the target box can be mounted by means of remote-controlled vacuum sealing of the ion tube.

The simultaneous operation of two neutron targets is assumed. The metal tungsten target with titanium coating, water moderators and beryllium reflectors will be used on the 1st stage.

The multiplying targets with the limited gain factor (up to 15-20) are to be used in the second box.

At the first stage the target based on natural uranium in stainless steel cover, which is already designed and manufactured, will be used, creation of targets based on U^{235} and U^{233} is in prospect.

The main parameters of the target systems as the pulsed sources of thermal neutrons are presented in Table 1 for the proton beam from storage ring.

Table 1.

Target parameters		W	U^{238}	U^{235}	U^{233}
Average power	MWt	0.2	0.4	2.12	2.17
Background power	MWt	-	0.004	0.014	0.0063
Thermal neutrons pulse width*	μs	30	30	30	30
Multiplication		0.95	1.15	14.5	20
Lifetime of prompt neutrons	ns	-	-	45	44
Average thermal neutron flux density*	$^n/cm^2s$	$3x10^{12}$	$4x10^{12}$	$1.1x10^{13}$	$1.8x10^{13}$
Peak thermal neutron flux density*	$^n/cm^2s$	$1x10^{15}$	$1.3x10^{15}$	$1.2x10^{16}$	$2.1x10^{16}$
Repetition rate	pps	100	100	30	30

*for 3.5 cm part of water moderator.

Receiving a 100 μs beam pulse from the proton linac, the proton storage ring delivers 330 ns (or smaller) proton pulses to the neutron source. Extraction of the proton beam from PSR is carried out during a pause of the time structure of the linear accelerator. The PSR is built in the beam channelling as a part of the beam layout (Fig 5.).

The beam pulse compression is achieved by one-turn extraction as soon as the filling process is finished. The initial time structure is shaped to provide an azimuthal void to exclude the beam losses during the rise time of the kicker magnet field. In this case the ring magnet structure is adjusted as an isochronous one ie.

$$\alpha = \gamma^2, \qquad (1)$$

where α is a momentum compaction factor, γ is the energy.

There is no necessity to use the RF system to keep the bunch structure. Similar idea has been proposed and experimentally studied at the CERN. The condition (1) is satisfied in our case only approximately because α-values deviate along the bunch. The magnitude of deviation is $\Delta\alpha = 0.018$ for linear density of the particles $3 \circ 10^{11}$ m^{-1}, which corresponds to the extension of the length of the bunch of 2 m, that is negligible in comparison with the full length of bunch ~75 m.

Table 2.

Orbit circumference (circulation period)	102. m (430ns)
Number of storage turns	240
Maximum intensity per pulse	$3x10^{13}$
Stored beam emittance	3π cm.mrad
Max incoherent tune shift	-0.09
Peak current	11 A
Momentum compaction factor	0.371
Kicker-magnet strength	0.02 T.m
Kicker- magnet rise time	100 ns

The creation of intense neutron sources on the base of proton 7.5 GeV synchrotron (SIN-45) is regarded as second stage of development of the complex of neutron sources of the Moscow Meson Factory. the construction two rings is assumed, the first one - fast-cycling proton synchrotron with the energy 7.5 GeV and mean current 250 μA at 50 pps with charge-exchange injection from linac and one-turn extraction, the second one - the beam stretcher.

The one-turn extraction to two independent neutron targets will allow one to create the next-generation complex of neutron sources with unique characteristics. The first target is assumed to be the Pb-Bi eutectic target with the forced circulation designed for frequency 40 pps (200 μA). The second target is assumed to be the multiplying system based on plutonium or uranium oxide in stainless steel cover with the sodium cooling.

The possibility of extracting part of proton beam from synchrotron to stretcher is foreseen to provide research work in kaon physics.

It's known that the production of secondary neutrons is most efficient at the proton energy 1.5-2 GeV. It can be explained by competition between nuclear interactions and ionisation losses in target. For the energies less than 1 GeV the direct ionisation losses of protons prevail and for the energies above ~1 GeV the ionisation losses due to electron-proton showers initiated by π^{o}-decay begins to work. With the growth of energy the efficiency of secondary neutrons production falls down, but the decrease of specific radiation damages of the target first-wall material becomes very significant that is the main problem of reliability of the system. The decrease of the beam volume charge and collective effects.

The dependence of radiation damage of the first wall by primary protons upon energy of primary protons calculated for a unit of mean density of thermal neutrons on the surface of water moderator is presented on Fig 6.

Comparative characteristics of operating and being designed pulsed neutron sources intended for research mainly in solid state are presented in Table 3.

Table 3.

Facility	Type	Av current on target	$\bar{\Phi}$ n/cm²s	$\hat{\Phi}$ n/cm²s	$K = \frac{\bar{\Phi}_T}{\Theta_T^2}$	Notes
IBR-2	pulsed reactor 4 MW	PuO_2+Na	10^{13}	10^{16} (120μs)	1	design parameters K~1/6
ISIS	PS, 70MeV-0.8 GeV	0.2 mA U^{238}	$2.1x10^{12}$	$1.4x10^{15}$ (30 μs)	3.4*	oper 0.12 mA
MMF IN-06	storage ring 0.6 GeV K_M=20,2 MW	0.5 mA U^{238}.	$4x10^{12}$	$1.3x10^{15}$	6.4*	under constr
		0.15 mA U^{233}.	$1.8x10^{13}$	$2x10^{16}$ (30 μs)	30*	project
Europ projec	storage rings 1 GeV	6.3 mA Pb-Bi(?)	$6.3x10^{13}$	$4.2x10^{16}$	100*	discussion
SIN-45	PS, 0.6GeV-7.5GeV K_M=20,8 MW	0.2 mA Pb-Bi,	$1.3x10^{13}$	$1.1x10^{16}$	26*	project
		0.05 mA U^{233}-Na	$1.2x10^{14}$	$4.5x10^{17}$	195*	discussions

* IN-06 target-moderator geometry (thin Be reflector)
** thick Ni reflector (factor ~ 4)

In conclusion we would like to express our best acknowledgements to: A P Alexandrov, M A Markov, Z P Zarapetyan, V N Aseev, S K Esin, V A Fedchenko, N A Kazarnovsky, N A Khryastov, E A Koptelov, P N Ostroumov, S V Serezhnikov, Yu P Severgin, I A Shukeylo, N I Trushkin, M T Vorontsov for useful discussion, support and co-operation.

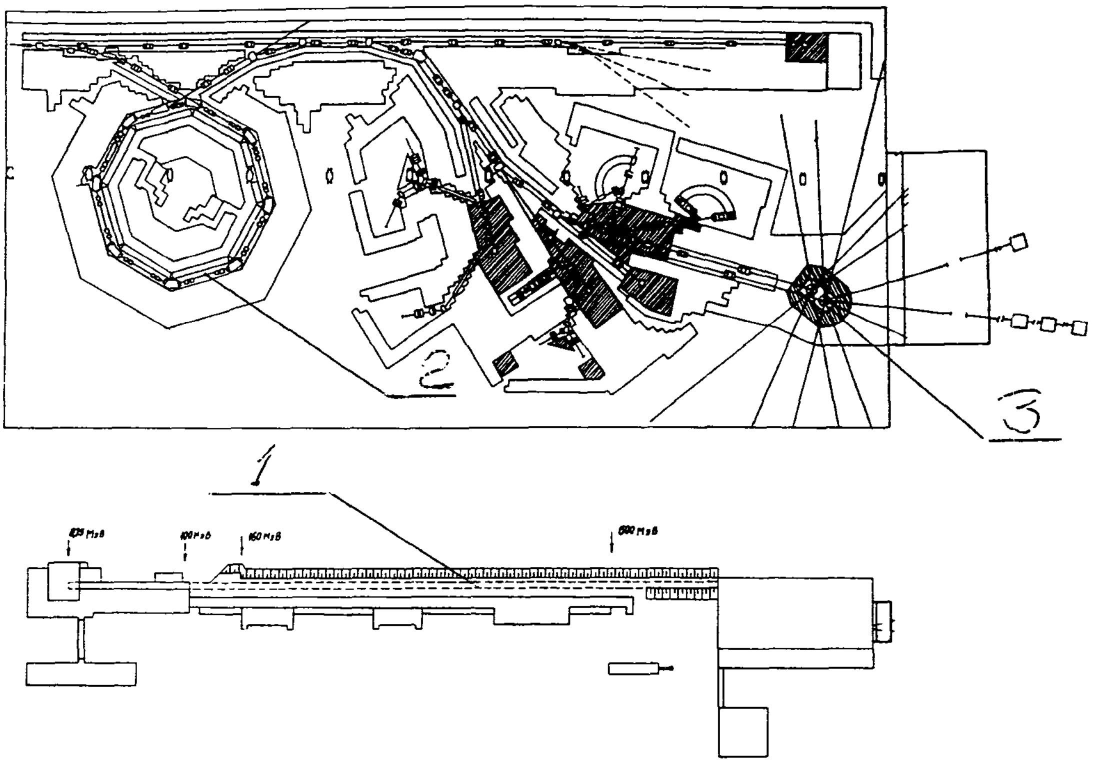

Fig. 1. Scheme of pulsed neutron source IN-06 of Moscow Meson Factory
1 - linear accelerator, 2 - ring compressor, 3 - neutron source

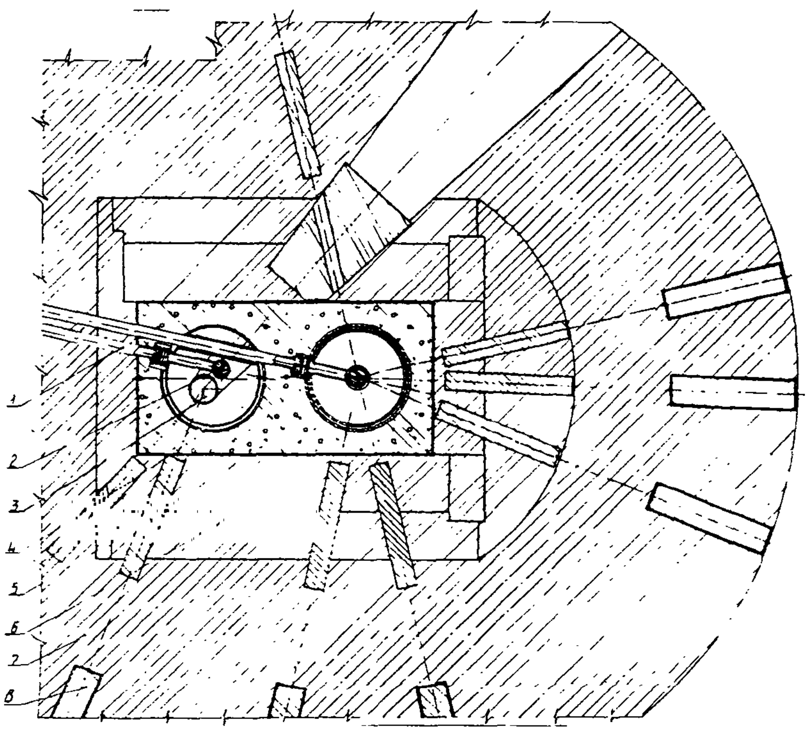

Fig. 2. Neutron source. 1 - proton beam line, 2 - target, 3 - vertical channel,
4 - vacuum tank, 5 - heat shield, 6 - iron shield,
7 - heavy concrete shield, 8 - shutter

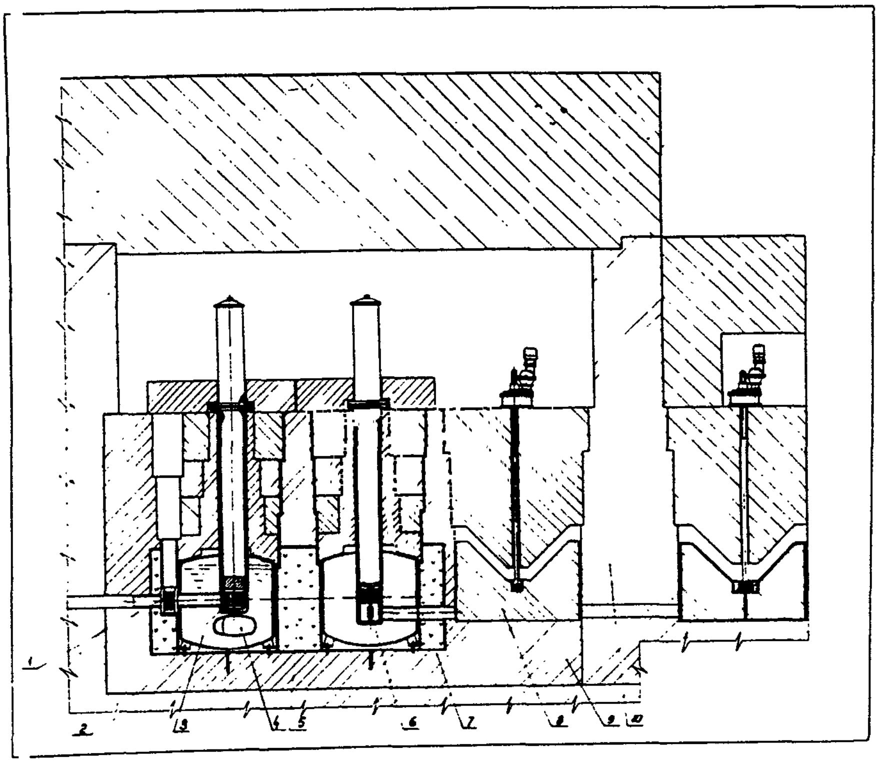

Fig. 3. Neutron source.

1 - remote-controlled vacuum sealing, 2 - neutron target, 3 - vacuum vessel, 4 - neutron channel, 5 - heat shield (iron with water cooling), 6 - water moderator, 7 - neutron channel, 8 - shutter, 9 - iron shield, 10 - heavy concrete shield

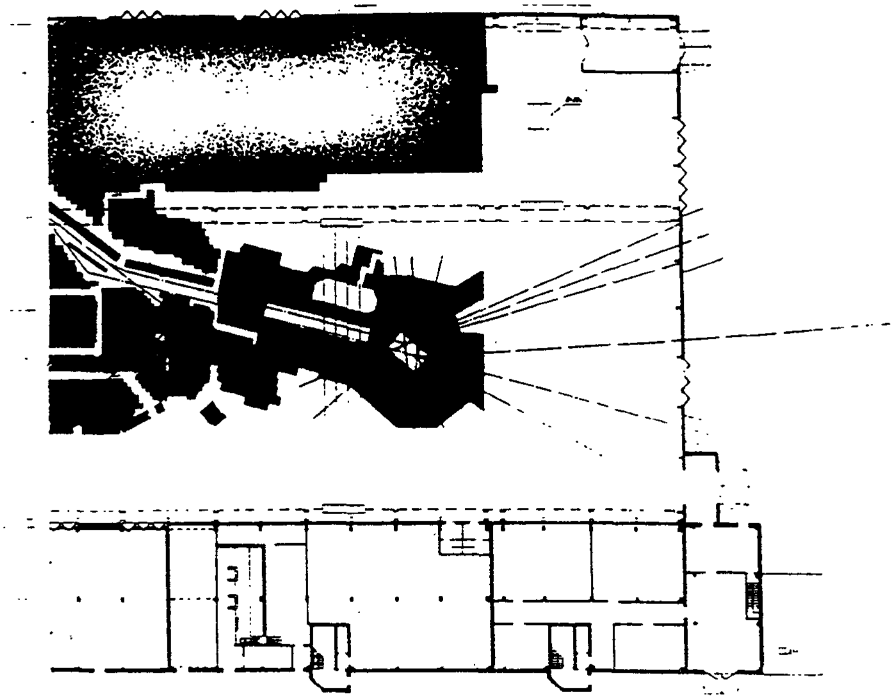

Fig. 4. Placement of the neutron source in the experimental hall

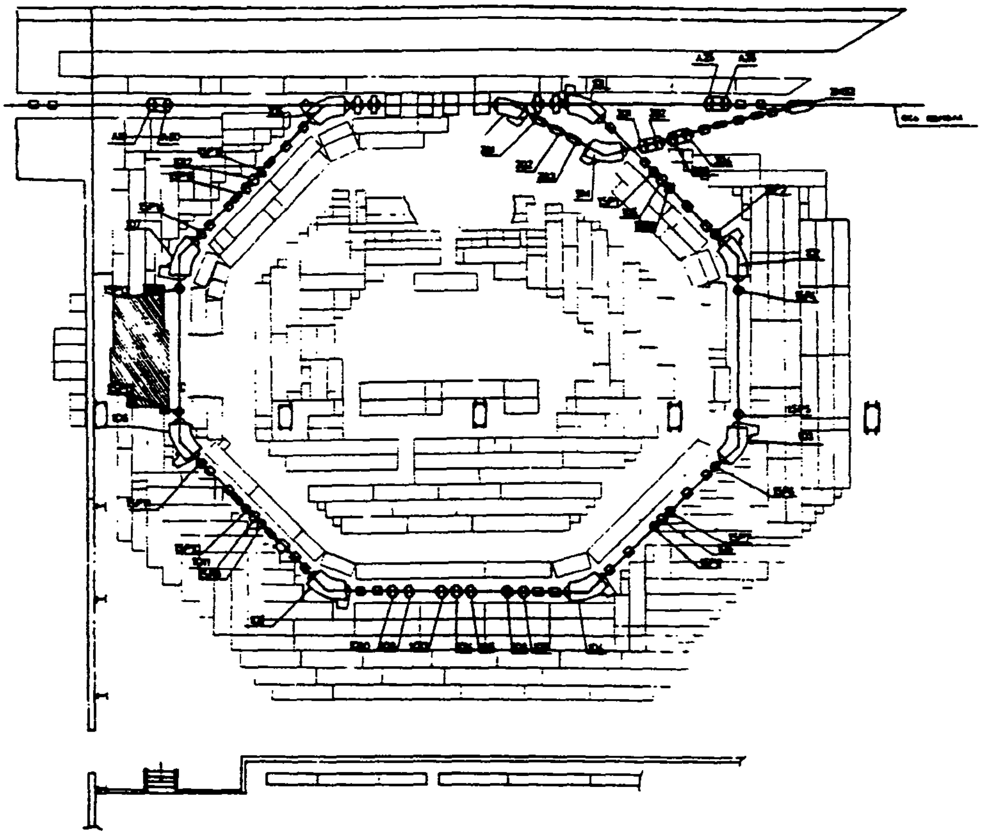

Fig. 5. The proton storage ring.

1D1-1D8 - the mine dipole magnets, B=1.45 T, aperture 20x12 cm², HORxVERT, bending angle=45°: 1Q1-1Q15 - the quadropoles, d=20 cm, length=0.4m, G=4.5 T/m: 1SP - the sextupoles: d=20 cm: 2B1-2B8 - the bump magnets for injection: 3K - kicker magnet for one turn extraction

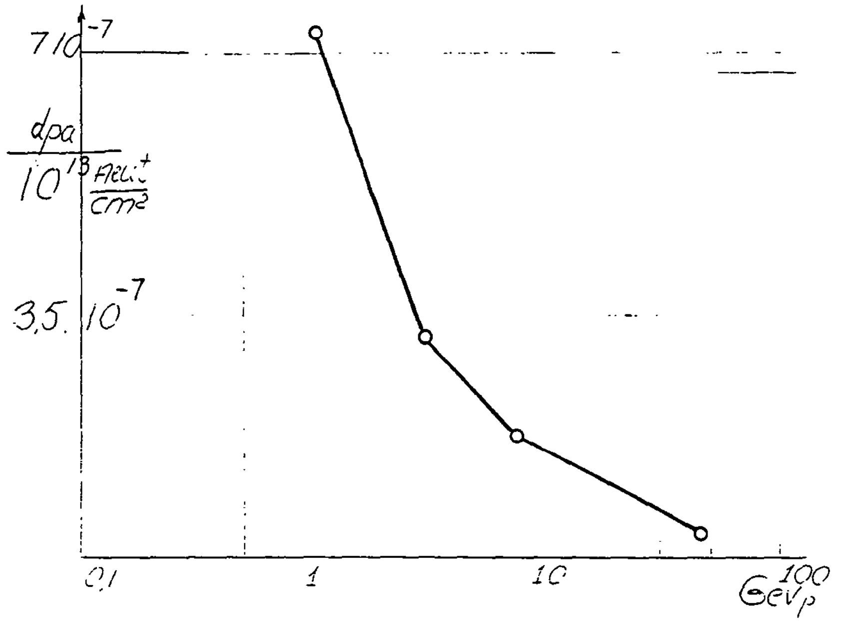

Fig. 6. Radiation damage of the first wall for 10^{13} neutrons per cm² of water moderator surface for protons (beam cross-section 20 cm²)