ICANS-XV
15th Meeting of the International Collaboration on Advanced Neutron Sources.
November 6-9, 2000
Tsukuba, Japan

23.7

NEUTRON TARGETS OF MOSCOW MESON FACILITY STATUS, PROBLEMS, PROSPECTS

S.Sidorkin*, E.Koptelov, A.Perekrestenko, Y.Stavissky, V.Trushkin, N.Sobolevsky

Institute for Nuclear Research RAS, 60-th October Anniversary prospect, 7a, 117312 Moscow, Russia
*E-mail: sidorkin@al20.inr.troitsk.ru

Abstract

The status, problems and possible perspectives of target complexes of the Moscow meson factory is described in the report. The results of test proton beam session to neutron source are analysed. Some technical features of targets and expected modes in the nearest sessions are stated.

1. Introduction

The defined progress in development of Moscow meson factory was made for past 2.5 years.
Now linear accelerator have following parameters: proton current is 150 μA (1998 year.- 70 μA), energy of particles is about 305 – 365 MeV, pulse repetition rate – 50 Hz. RFQ – system was installed in an initial part of the accelerator. It has increased time of stable operation of accelerator up to ~ 90%. Besides in an initial part of the accelerator the chopper is installed for support of physical experiments by short pulses of protons. The technical condition of the accelerator allows supporting a current up to ~ 300 μA with pulse repetition rate 100 pps, but this possibility is not realized because of outstanding works on the experimental area /1/.
This progress has stimulated a works on the neutron complex of INR. Now structure of a neutron complex of INR include: complex of neutron sources, beam stop, 100 t lead slowing-dawn neutron spectrometer, solid state spectrometers and accompanying infrastructure ensuring operation of this facilities (fig.1).

2. Beam Stop

The beam stop (fig.2) consists of a changeable ampoule containing water-cooled tungsten plates. Inside an ampoule there is a vertical channel for irradiation of objects by a diameter ~ of 50 mm and height 100 -150 mm with autonomous cooling. Removable ampoule is placed inside heat shield and is closed by steel plugs /3/.
Main functions of beam stop on experimental area is next:

- Reception of a perturbed beam after passing by it thin targets of experimental installations,
- Transmitting of proton beam across beyond beam stop,
- Carrying out of physical experiments with use of the channel for irradiation of samples,
- Irradiating of structural materials in the mixed proton and neutron fields with their consequent delivery in hot laboratories IPPE (Obninsk) for researches.
- Isotopes production.

The degree of readiness of object is evaluated in 95%.
The top part of a radiation shield is not finished. The experimental zone (above the beam stop) is equipping by the irradiation channel loading and unloading machine and monitoring.
Water coolant is in vessel of beam stop during 3.5 years. Is not observed of visible consequences of corrosion, at the present, though the water-chemical regime of the coolant was not ideal. It is the indirect certificate of a regularity of choice of Ti-coating as corrosion protection for Al and W units and maintenance of their compatibility /4/.

Inspection of internal surfaces of beam stop is in the nearest plans. The purpose of the inspection is the determination of a condition of surfaces, channels and velocity of corrosion. The possibility of such inspection is stipulated by low activation of the beam stop in the last proton session. This data are necessary for assembling of the second ampoules of a beam stop and a neutron source with the Be-reflector. Some modifications of cassettes with tungsten plates will be made during assembling.
Primal problem of the beam stop is provision of reception 50 μA of proton current.
The following experiments with use the beam stop are studied:

- Imitation of conditions characteristic for radiation layers of the Earth. Experimental researches of an electronic engineering intended for long-term working in space.
- Measurement of a rate generation of radiation damages in metals at cryogenic temperatures by a measurement of an electrical resistance.
- Research of radiation stability of perspective structural materials of nuclear engineering. Development of express – tests of materials /5/.
- Research of structural transformations in magnetic and unmagnetic materials under irradiation ones by the mixed proton and neutron fields.

The beam stop can be modified. Special liquid metal insertion (Pb-Bi, Hg, Pb) with pipe specimens under gas pressure can be installed instead of irradiation channel. In this case the pipe specimens will be under influence of several permanent factors simultaneously such as mechanical stress, liquid metal, irradiation by the mixed proton and neutron fields, temperature gradient and so on. At that, the local heat release density ~ 1kW/cm^3 can be obtained in the stainless steel specimen at acting of the narrow proton beam (diameter ~ 1 cm) /6/.

3. Complex of neutron sources

3.1. Pulse neutron source.

Pulse neutron source is located in the first box of a radiation shield (fig.3) and is intended for a research of solid and nuclear – physical experiments /2,3,4/.
.This neutron source (scheme is represented on fig.4) naturally compensates shutting of research reactors in Moscow which have been used for physical experiments. It is basis for creation of the new research center near Moscow approximately hour' journey from majority of the interested institutes of Russian Academy of Science and Ministry of Atomic Energy. Some scientific groups are moving in INR one's the experimental facilities.
The water-cooled tungsten target without Be-reflector is installed as neutron source now.
The first neutrons on the pulse neutron source were received during a test short-term session in end of 1988 year. The purpose of this session was examination of all systems of the experimental area providing the beam guide. The proton beam directed on the target during session had the following parameters: current have been ~ 0.01 – 3 μA in different moments of time, proton energy ~ 209 MeV, pulse repetition rate is about 1 pps, duration of proton pulses ~ 60 mks. Instrumental neutron spectrum of upper moderator is shown on fig.5.
Some modifications in control systems were made after test session. In particular, new detector of beam position is being installed before the target /7/.
The works at the storage of a liquid radioactive waste providing collection of coolant of first loop are finished.
The top part of a radiation shield is not finished. Without it sessions for checking systems of the experimental area providing the beam guide and studies of characteristics of neutron source and spectrometers is possible only.
The degree of readiness of object is evaluated in 95%. Next sessions will carry out after finish of assembling of the lead slowing-dawn neutron spectrometer and adjustment of spectrometers for researches of solid.
There is next plan for development of a neutron source with the purpose of increase of a neutron flux in account on one initial proton:

- Mounting of the new tungsten target with Be-reflector enveloping upper moderator (target is under assembling). It will increase the thermal neutron flux about 1.8 – 2 times.

- Modification of the existing W-target. (Mounting of the Be-reflectors on upper and lower moderators, a number of modifications into a construction of the target). The possibility of realization of this point is stipulated by low activation of the existing target.
- Mounting of the U-target with fuel elements on base of natural uranium of a high density that will increase neutron flux about 1.4 times in additionally /4/. Almost all details of target are ready.
- Creation of the multiplying target with the multiplication < 10, for magnification of neutron flux ~ 3 - 4 times in comparison with the target on base of natural uranium /4/. This stage of the program closely is connected to the program of creation of a neutron source in second target boxing.

3.2. *Multi-purpose neutron source in the second box of radiation shield.*

The second box is free at the present. From above the box is closed by steel shielding plugs to ensure acceptable radiation conditions at work of a neutron source located in the first box. The degree of readiness of an accompanying infrastructure of the object, which is common for both boxes, is ~ 95 %.

Earlier in this boxing of radiation shield was planned to place a quasi-stationary neutron source for search of n-ñ oscillations and direct measurement of length of neutron – neutron scattering /2,3/.

In an inheritance from these initial plans in the radiation shield have remained four the neutron guides and the through wide-aperture channel.

On a basis of this channel it is possible to organize an extraction of not less six neutron beams with the help of system of collimators, located inside the channel and two bent neutron guides. In this case ten neutron beams will be deduced from the second box of radiation shield

However there is large vertical diversity between the axis of a proton beam and axes of neutron guides (reaching 47 cm for the lower group of neutron guides, consisting from 8 channels) and large distance between axes of neutron guides located above and below than target (67 cm)

Without essential reconstruction of radiation shield these sizes can be reduced only at the expense of change of a moderator diameter in limits of neutron guides with the appropriate installation of collimators.

Therefore the following "scripts" of creation of a neutrons source in the second box are possible:

- To perform the W-target ensuring the maximum possible flux of neutrons only in two upper channels, located above level of a proton beam on 20 cm. Neutron flux in other channels is provided according to technical possibilities. Such way makes the extremely ineffective 8 channels located below level of a beam on 47 cm.
- To displace a proton beam maximum down (~ 5 cm), as far as a diameter of proton guide allows. Moderators located above and below level of the proton beam should be approached to the target in a maximum way, having reduced diameter up to 10 cm with appropriate installation of collimators in neutron guides. In this case vertical offset between an axis of a proton beam and centers of moderators will be accordingly ~ 20 and ~ 32 cm. It will increase flux in the lower moderator leaving in the wide-aperture channel (~ 6 neutron beams) and will decrease in upper moderator (2 neutron beams). Two neutron guides located below proton beam will be excluded from work completely. The neutonics of such source will be still far from optimum.
- To use the multiplying target and to ensure a high flux of thermal neutrons in all channels for a radical solution of a problem.

However, the multiplying neutron source with a direct action on uranium core of the intensive proton beam (300-500 μA) will be too expensive in exploitation because of a short lifetime of such target and necessity of frequent replacement of target modules.

So, for example in the ISIS, the lifetime of all uranium (not multiplying) targets with disk elements has been disappointingly short (several months). At this a mean current of protons did not exceed ~ 150 μA /8/.

If to suspect, that with cylindrical fuel elements and other high-density uranium alloys /4/, lifetime of the target will increase in two, three and more times, it will be obviously insufficient for the multiplying target.

The running time of core of the pulse reactor IBR-2 (JINR) is already ~ 10 years /9/. Therefore scheme of the uranium target with a direct action of a beam on core more correspond to currents ~ 5-30 μA (KEK /10 /, IPNS /11. /) where achieved rather long terms of exploitation.

In this case (for second cell of a radiation shield of MMF at proton current ~ 300 – 500 μA) the scheme like accelerator-driven subcritical systems (ADS) is more corresponding to the multiplying neutron source (W or Pb-Bi easily removing target module and a multiplying blanket).

However in this case horizontal input of beam in the target and positions of moderators complicate its realization strictly connected to neutron channels.

Some approaches to the scheme of the multiplying target also may be. The calculations and initial studies of different versions of such neutron source are now carry out with the purpose of finding the optimal configurations of the target, blanket and moderators.

Certainly the scheme of the multiplying target with central W - target is less effective, than classic from the point of view of a neutronics. The number of primary neutrons per incident proton generated in W or Pb-Bi target is about 1.4 times less than in uranium target /4/. Therefore the multiplying coefficient should be higher approximately the same value in comparison with classic target for compensation only of this loss.

However the following advantages compensate this lack:

- The subcritical assembly is outside of a direct action of the proton beam and has a long term of exploitation (~ 10 years),
- The conditions for maintenance of nuclear safety of the object because of absence of often manipulations with fuel are much better,
- There is no necessity to use dense uranium alloys. Quite enough to use well of itself recommending in nuclear engineering of kinds of fuel including oxide fuel,
- The separate changeable tungsten target module has much more lifetime in a comparison with the uranium target /8/,
- The system of moderators also can be made as separate changeable modules that increase experimental possibilities of source,
- Besides there is a possibility to simulate and experimentally study some aspects electronuclear and transmutation systems. It essentially expands the list of the organizations interested in cooperation and accordingly basis for creation of such facility.

The possibility of using of similar source for analysis of problems of an electronuclear way for energy production and nuclear transmutation is based on the following circumstance.

The proton beam with energy 360 - 600 MeV creates inside extended targets (Pb-Bi, W etc.) an initial spectrum of neutrons (spectrum of evaporating neutrons) practically completely conforming with spectrum at energy of a beam 1.2 - 1.3 GeV (fig. 6). The full output of neutrons from the leaden target is presented in fig. 7 /12,13,14/. The identity of spectra of an external source allows to imitating the basic neutron-physical features of the full-scale facility on a demonstration stand. Such stand created from special changeable modules should have simultaneously features of the Large Physical Stand (БФС) and reactor BR-10 (IPPE, Obninsk). The modular principle of construction of the stand would allow experimentally studying various configurations ADS. The maximum size of modules, from which the stand could be assembled, is dictated by sizes of intermediate storages for ampoules of a neutron source. The power of the stand could compound ~ 6 MW at a multiplying coefficient ~ 10 and achievement by the linac of design parameters (500 μA, E_p = 600 MeV).

The vertical channels for irradiation samples and productions of isotopes should be stipulated in the stand.

The installation would allow finishing a cycle of researches for an electronuclear method of production of energy and nuclear transmutation and providing complex checks of the various concepts and obtaining a technological experience on the demonstration stand INR RAS.

Besides the cavity of a wide-aperture channel inside a radiation shield is the most suitable place for neutron therapy. In this case the special cell can be placed about 5 m from source. It essentially increase fluence of neutrons, allows to use existing technology of Institute for Radiation Medicine (Obninsk), and also to compensate future closing of the reactor BR-10 in IPPE - Obninsk used now for this purpose.

At the present the basic specifications and philosophy of a multi-purpose stand are formulated, the coordination with IPPE and *ОКБ* "Hydraulic press" is conducted.

The alternative versions of creation of a neutron-source in the second cell are simultaneously considered.

4. Lead slowing-down neutron spectrometer

100 t Lead slowing-down neutron spectrometer /2/ is palsied near radiation shield of complex of neutron sources (fig.1). It can be used for researches in the field of fundamental and applied physics and radiation medicine.

The physical features of the lead slowing-down neutron spectrometer dictate the following main requests to construction:

- Minimum quantity of structural materials in order to reduce the inelastic scattering of neutrons,
- The minimum quantity of cavities in order to reduce leaving of neutrons from the slowing down process.

These effects increase duration of neutron pulse in slowing down process and decrease a resolution of spectrometer.

The mounting of the lead slowing-down neutron spectrometer is completed. The continuous lead target with air coolant has installed in spectrometer now. Therefore intensity of the beam directed on the target is limited to a current ~ 1 μA.

In future we suppose using liquid metal Pb-Bi target with power ~ 30 kW and air cooling for increasing of neutron intensity of spectrometer (fig.7).

The main technical characteristics of the Pb-Bi target should be following:

- Diameter of target in lower part is about 32 cm. This dimensions a little exceeds the range of protons with energy ~ 600 MeV in Pb-Bi and corresponding to diameters of temporary storage's
- Temperature of Pb-Bi eutectic is about 200 °C in order to the electromagnetic pump had maximal efficiency and a minimal corrosion rate of container take place.
- Diameter of proton guide is 60 mm within spectrometer. Therefore maximum density of heat release in a stainless steel will not exceed ~ 50 W/cm^3 and the maximum density of thermal flow on surface of the container will be ~ 5 – 7 W/cm^2 in depending on a thickness of a wall. Accordingly, speed of coolant in window region will not exceed ~1 m/s.
- Height of the target ~ of 1.5 m. Upper part of Pb-Bi target must be beyond lead spectrometer in order to remove the main quantity of heat from target outside of cube and do not transfer the additional heat to the surrounding layers of lead (fig.8).

The electromagnetic pump can be required for initiation and support of natural convection and reductions of period for formation of convection. The difference of pressure between rising and descending parts of flow can be insufficient for maintaining this process because of small height of the target.

High intensity is one of the main advantages for the 30 kW lead slowing down neutron spectrometer. This spectrometer can be beyond comparison for researches of cross-section of rare nuclear reactions and reactions with micro samples (10^{-12} g) in that part where energy resolution is not determining.

Apart this spectrometer can be a prototype of electronuclear facility with the slowing-down neutron spectrum /15/.

Low level of γ - rays and the rather small sizes of spectrometer allow to organize the medical channel for neutron therapy with good background conditions.

Negotiations about financing of Pb-Bi project between INR, IPPE and Ministry of Atomic Energy are carried on.

5. Conclusion

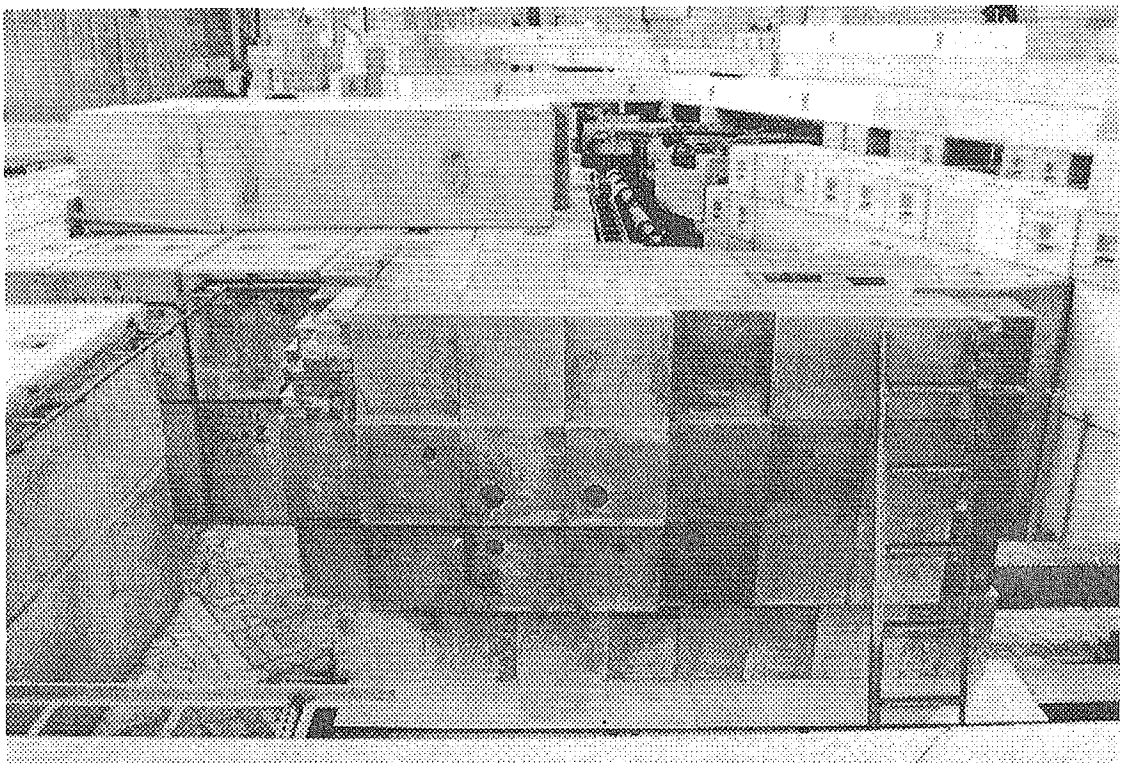
The program for advance of multiple-purpose neutron sources of MMF is developing by experts of Russian Academy of Science and Ministry of Atomic Energy. Further development of neutron sources of MMF will depend on this program. The authors are grateful to the employees of the research and design organizations of the Ministry of Atomic Energy (IPPE, OKB "Hydropress", ITEP and al) for discussion of the problems affected in the paper.

Reference

1. L.V.Kravchuk. Proton Linac of the Moscow Meson Factory for the ADTT Experiment. Proc. of the Inter. Workshop. Nuclear methods for Transmutation of Nuclear Waste. Dubna, Russia.
2. Y.Y.Stavissky. Spallation Neutron Sources at the INR RAS: Present Status and Prospects. ICANS-13, PSI, Switzerland, p.63,1995.
3. M.I.Grachev, M.V.Kazarnovsky, V.V.Khmelschikov, N.A.Khryastov N.V.Kolmychkov, V.M.Lobashev, V.A.Matveev, M.N.Ospanov, V.N.Sazanov, S.F.Sidorkin, Yu.Ya.Stavissky, V.I.Trushkin, M.T.Vorontsov. Pulsed and quasistationary neutron sources based on proton beam of Moscow meson fasility. Proceedings of the Eleventh Meeting of the International Collaboration on Advanced

Neutron Sources ICANS-11, V.1, p.454. KEK, Tsukuba, Japan, October 22-26, 1990. KEK Report 90-25. March 1991.

4. A.V.Dementyev, V.G.Miroshnichenko, S.F.Sidorkin, N.M.Sobolevsky, Y.Y.Stavissky, I.I.Konovalov, A.A.Maslov, I.I.Tretyakov, V.I.Truskin, A.D.Rogov. Tungsten and Uranium target for Moscow Meson Factory. ICANS-13, PSI, Switzerland, p.461, 1995.
5. E.A.Koptelov, S.G.Lebedev, O.N.Smirnova, et al. Prospect for study of radiation damage at RADEX-15, radiation experiment facility, based on the beam stop of Moscow Meson Factory. Journal of Nuclear Materials 233-237 (1996) 1552-1556.
6. S.F.Sidorkin, G.S.Bauer, Y.Dai, M.I.Grachev, L.V.Kravchuk, Y.I.Orlov. Opportunities for Irradiation Studies of Structural Materials for Neutron Sources at the Proton Beam-Stop of Moscow Meson Factory. ICANS-XIV, June 14-19, 1998, Starved Rock Lodge, Utica Ill., USA, p.301.
7. A. Tron, Secondary Electron Monitors in Linacs for Intense Neutron Sources. Proc. of the LINAC94 Conf., 21-26 Aug. 1994, Tsukuba, pp. 917-919.
8. T.A.Broome. Prospect for targets and methane moderators at ISIS. ICANS-13, p.632-639.
9. V.A.aksenov, V.D.Ananiev, A.V.Belushkin, A.V.Vinogradov. The IBR-2 fast pulsed reactor: present and future. ICANS-14, June 14-19, 1998, Starved Rock Lodge, Utica Ill., USA, p.41.
10. H.Ikeda. News from KENS. ICANS – 13 and ESS – PM4. Villigen PSI, Switzerland, Oct. 11-14, 1995.
11. J.M.Carpenter, A.G.Hins. Experience with IPNS targets. ICANS-12, T-1.
12. S.F.Sidorkin, N.M.Sobolevsky, A.D.Perekrestenko. To a problem of the demonstrative electronuclear stand and research of nuclear transmutation. Proceedings of the International Conference on Sub-Critical Accelerator Driven System, Moscow, ITEP, October 11-15, 1999, pp. 91-101.
13. R.G.Vasil'kov, V.I.Yurevich. Neutron emission from an extended lead target under the action of light ions in the GeV region. ICANS-11, V.1, p.340. KEK, Tsukuba, Japan, October 22-26, 1990. KEK Report 90-25. March 1991.
14. A.V.Dementyev, N.M.Sobolevsky, Y.Y.Stavissky. Neutron yield from extended lead target under incident protons of 0.1 to 100 GeV. Nucl. Instr. and Meth. In Phys. Res. A374 (1996) 70-72.
15. C.Rubbia et al. Conceptual Design of a Fast Neutron Operated High Power Energy Amplifier.CERN/AT/95-44(ET), 1995.



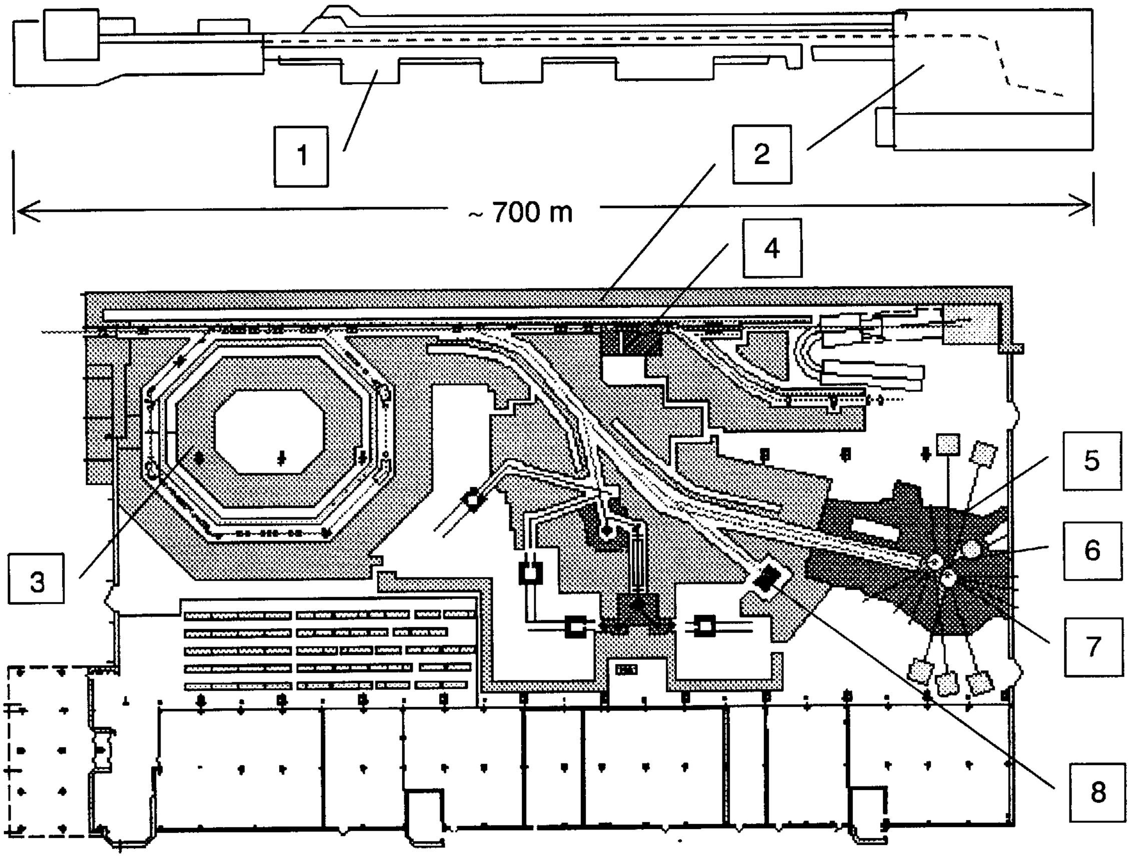


Fig.1. Proton linac and experimental area of MMF: 1- linac, 2 – experimental hall, 3 – storage ring, 4 – beam stop, 5 – complex of neutron sources, 6 – second (free) box, 7 – box of pulse neutron source, 8 – lead slowing-down spectrometer.

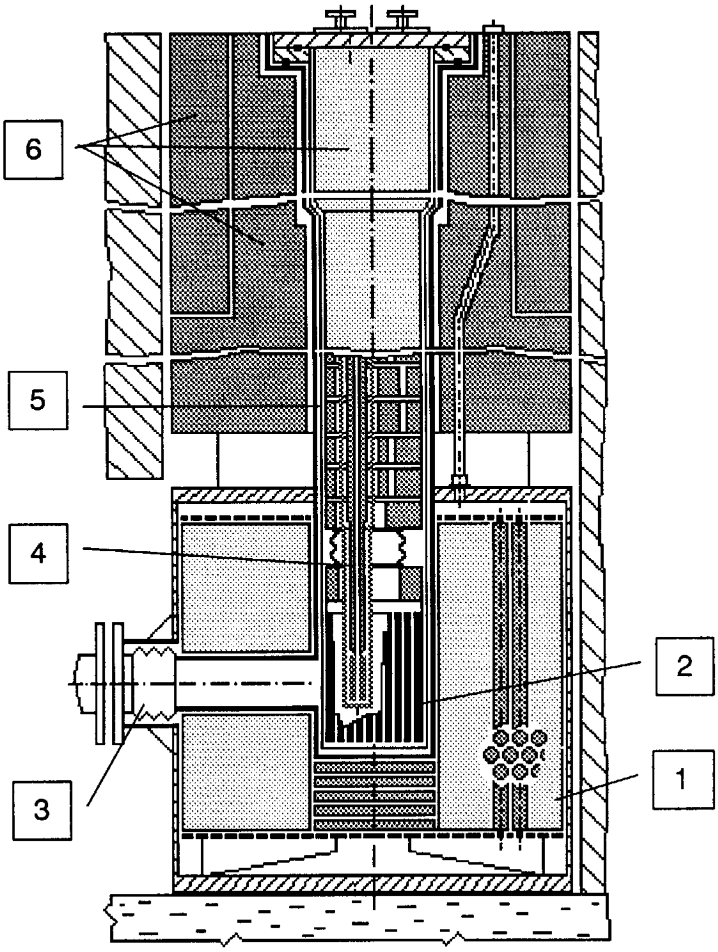
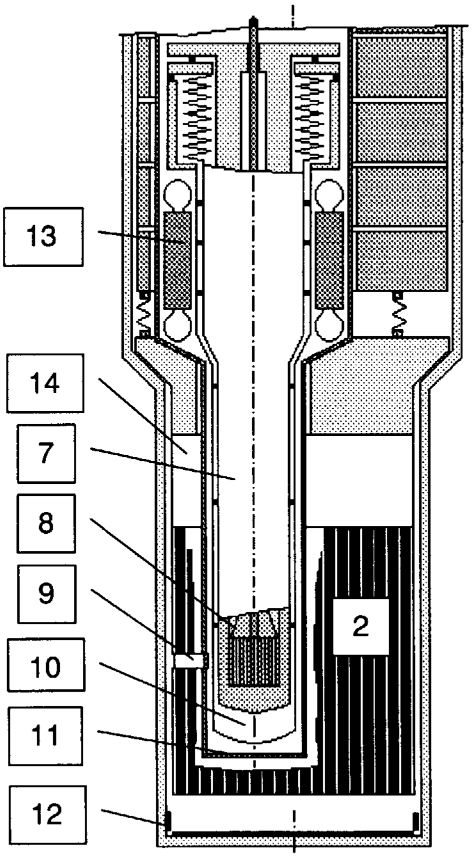


Fig.2a. Sketch of the present beam stop at the MMF:

1. - water cooled shielding,
2. - beam stop insert made of tungsten plates,
3. - proton beam channel,
4. - irradiation insert in thimble,
5. - aluminium vessel,
6. - removable top shield (steel plugs).

Fig.2b. Sketch of the proposed LM – irradiation insert that would replace the present irradiation insert, requiring only minor modifications to the tungsten plate assembly:

7. - liquid metal container,
8. - liquid metal,
9. - jet forming manifold for window cooling,
10. - outer container of stainless steel with gas atmosphere,
11. - receptacle for irradiation insert with water filled catcher volume,
12. - Al_2O_3 cover of the bottom part of the aluminium vessel for corrosion protection in case of LM leak,
13. - EM-pump,
14. - water cooland.



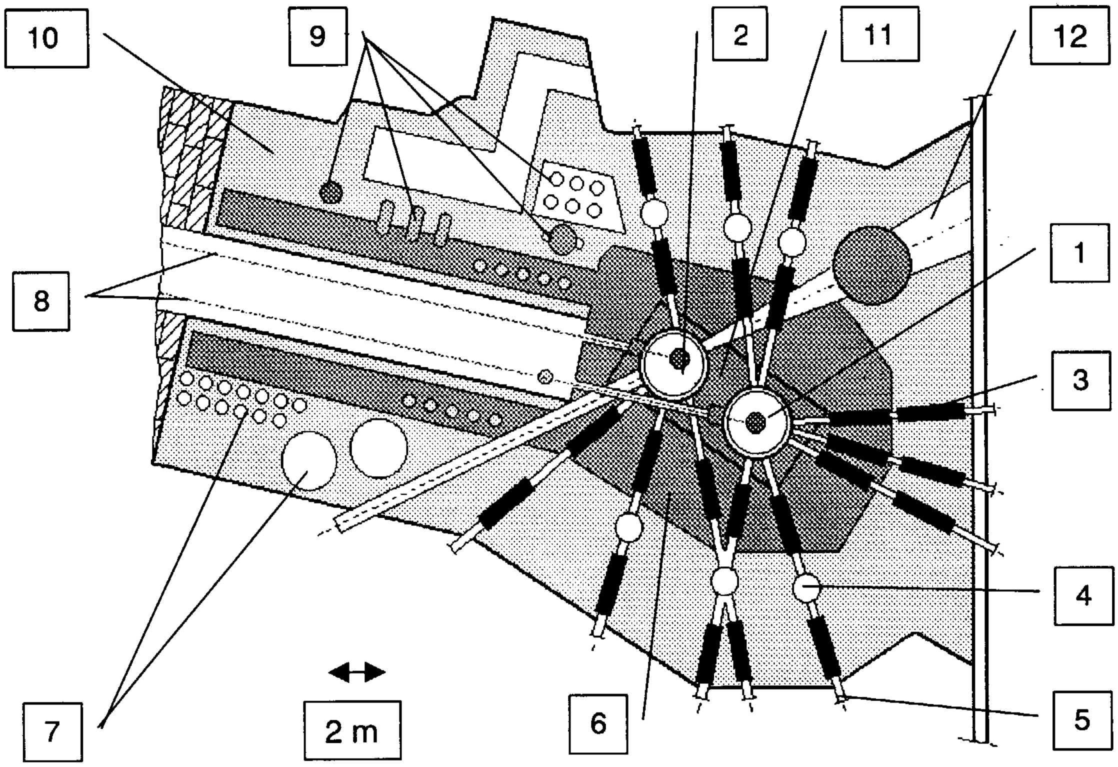


Fig.3. Assembly of neutron sources. 1 – cell of the pulsed neutron source, 2 - cell of demonstrated research stand, 3 – neutron gates, 4 – vertical channels for additional equipment, 5 – neutron guides, 6 – iron shield, 7 – storage's of radioactive tanks and ampoules (modules), 8 – proton guides, 9 – equipment of the first water loop (pumps, filters, heat exchanger and etc.), 10 – heavy concrete shield, 11 – heat shield, 12 – the wide aperture channel.

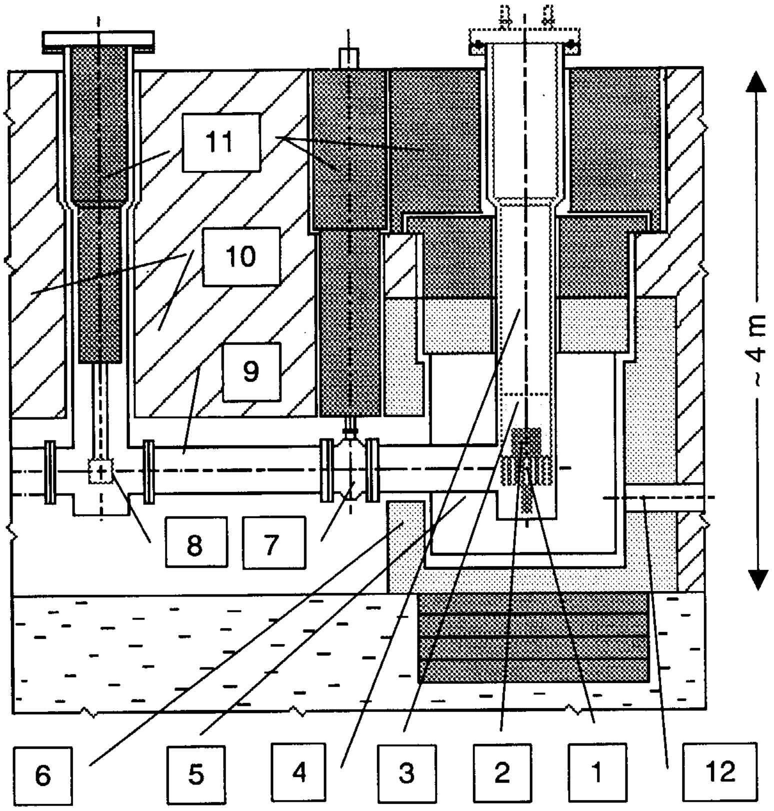


Fig.4. Scheme of the pulsed neutron source. 1 – tungsten core, 2 – moderators, 3 – beryllium reflector, 4 - the ampoule (the module) with shielding plug, W – core, Be - reflector and moderators, 5 – the gas tanks, 6 - heat shield, 7 – the remote-controlled vacuum sealing, 8 – the beam position sensor, 9 - proton guide, 10 - iron shield, 11 - the removable steel plugs, 12 – neutron guides.

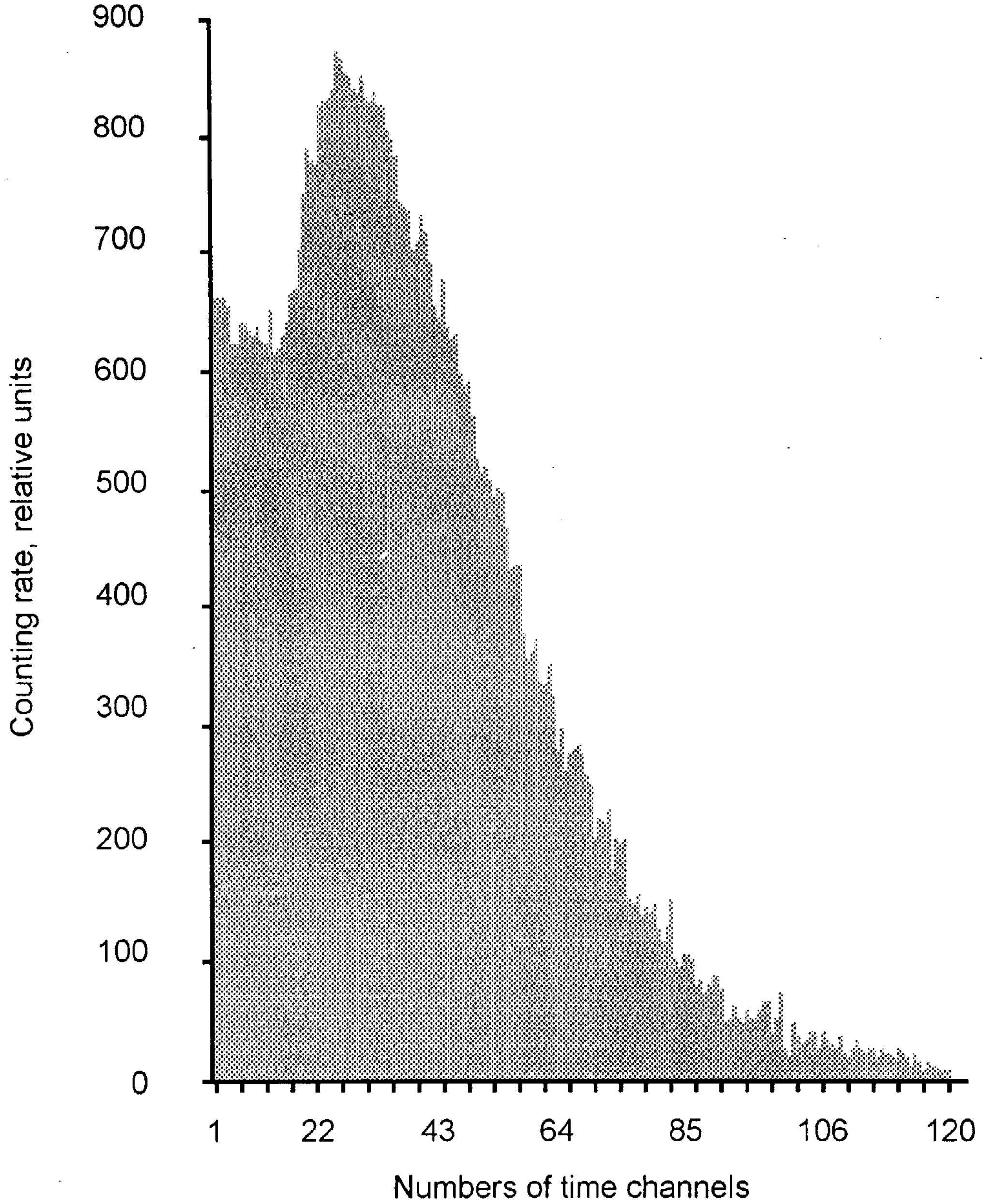


Fig.5. Instrumental neutron spectrum. Proton energy - E_p = 209 MeV, time of flight length – 10 m, wide of time channel - 128 μs, the parameters of neutron in 100-th channel: $E_n = 3.2 \cdot 10^{-3}$ eV, λ = 5.07 Å.

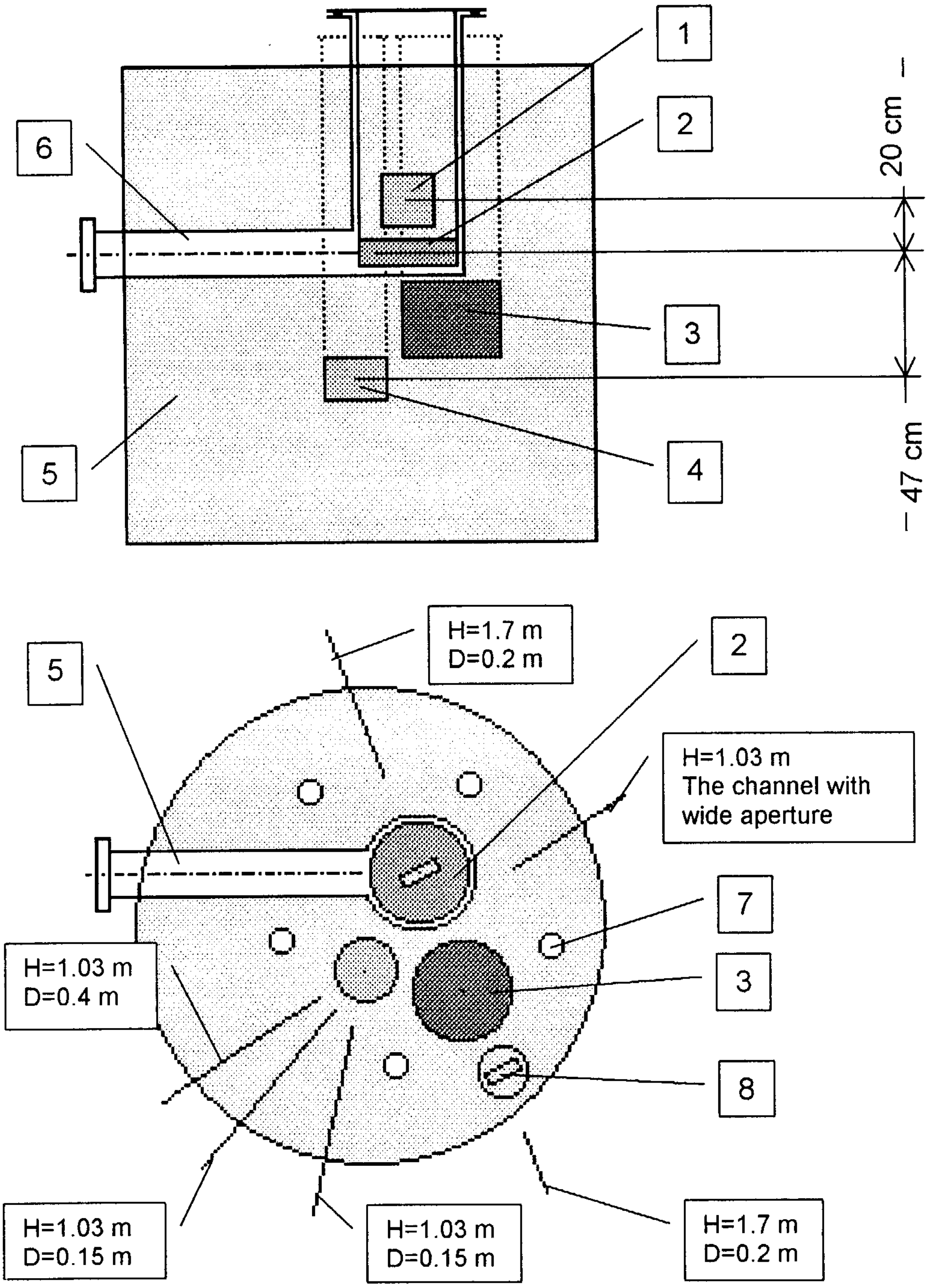
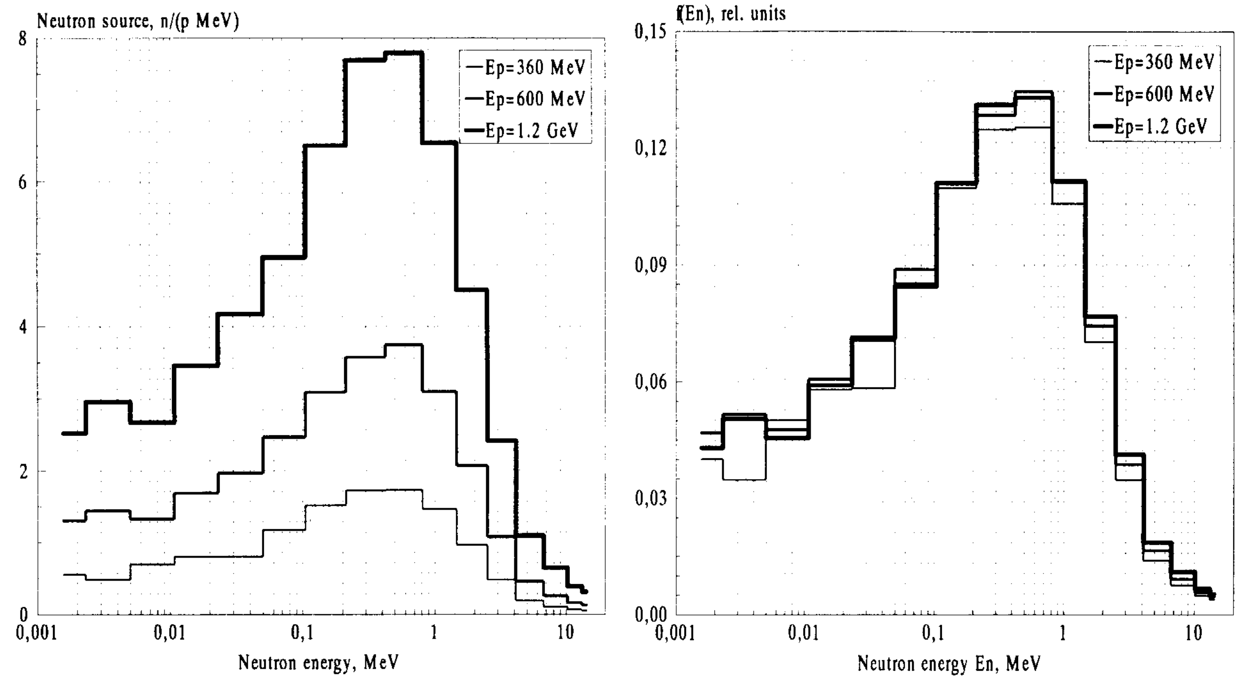


Fig.6. Scheme of disposition of neutron guides (heights and diameters are shown) and the main modules (one of possible variants) in the second box: 1 – upper moderator joined with target module - 2, 3 – module of subcritical assembly, 4 – module of lower moderator, 5 – Be-Ni reflector, 6 – proton guide, 7 – channel for irradiation samples, 8 – module of upper moderator.



a　　*b*

Fig.7. Spectra of neutrons generated inside of the cylindrical lead target (R=10 cm, L=60 cm) at irradiation by proton beam with energy 360, 600 and 1200 MeV: a) normalized on a yield, b) normalized on a one neutron.

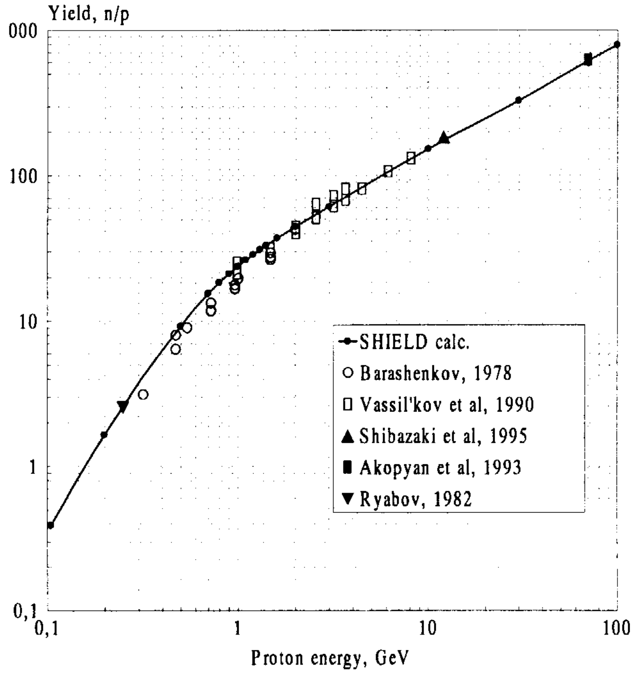


Fig.7

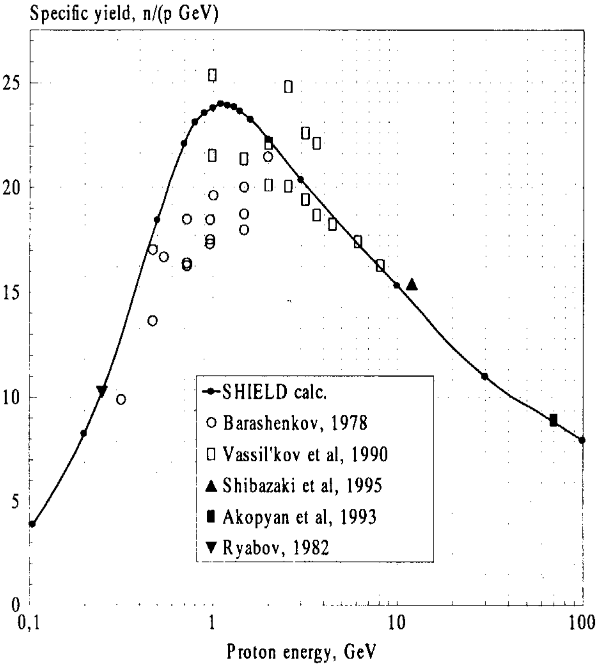


Fig.8.

Fig.8. Yield of neutrons with energies below 10.5 MeV from the whole surface of the cylindrical lead target (R=10 cm, L=60 cm) in dependence on the energy of proton.

Fig.9. Specific yield of neutrons with energies below 10.5 MeV from the whole surface of the cylindrical lead target (R=10 cm, L=60 cm) in dependence on the energy of proton.

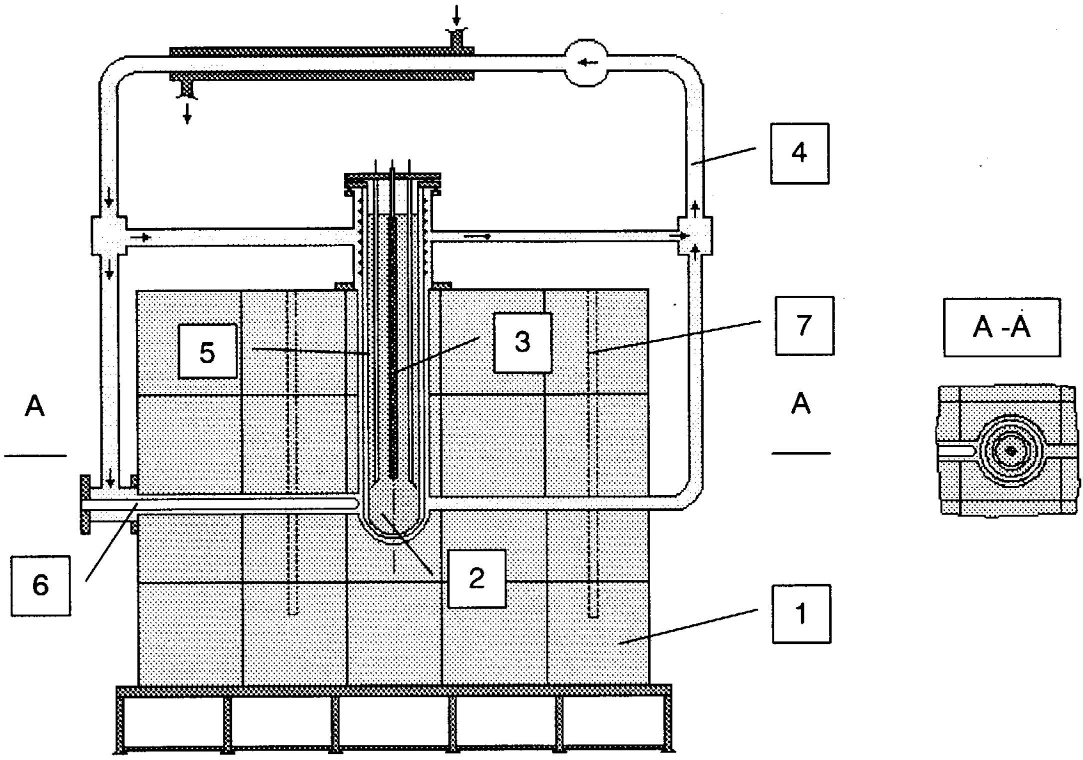


Fig.10. Lead slowing-down spectrometer: 1 – lead (3.0 × 1.8 ×1.5 ì ^{3}), 2 - Pb-Bi target, 3 – heater, 4 – loop of air cooling, 5 – divisor of the ascending and descending Pb-Bi currents, 6 – proton guide, 7 – channels for samples.