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SPALLATION NEUTRON SOURCES AT THE INR RAS: PRESENT STATUS AND PROSPECTS

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ABSTRACT

The paper presents the program of development of spallation neutron sources for research in nuclear and solid state physics, radiation damage physics, problems of the weapon plutonium utilization and nuclear waste transmutation.

1. Introduction

The INR RAS is developing the program of creation of intensive neutron sources driven with the high-current proton linac of the Moscow Meson Factory for studies in nuclear and solid state physics and for applied studies.

The program relies on the Monte Carlo simulation of spallation and fission neutron generation and interaction with medium [1, 5].

The construction of the intensive pulsed slow neutron source IN-06 [4] based on the proton linac [2], storage ring [3] and tungsten or natural uranium silicide targets is near completion (1996). It is primariliy intended for studies in nuclear and solid state physics.

The multiplying uranium target with gallium cooling is under development (RIN-10, [5]). It will allow the slow neutron fluxes with peak and average densities as high as 10^{17} and 10^{14} n/cm^{2}s to be achieved.

This year the construction of the proton beamstop with the irradiation channel [6] should be completed. The fast neutron flux density as high as 10^{15} n/cm^{2}s·mA is to be achieved.

The super sensitive neutron spectrometer based on the neutron slowing-down in lead is under development. The spallation neutron generation rate in it will constitute $\sim 10^{16}$

n/s. Its prototype "Python" [7] with the intensity of $5 \cdot 10^{13}$ n/s is now being used for studying actinide's fission.

Certain efforts are directed towards the problems of efficient utilization of weapon plutonium and transmutation of long-lived fission products with high-current proton accelerators [8,9].

2. Methods for calculating the spallation neutron source characteristics

For calculations of neutron yield, heat deposition, nuclide production and radiation damages in targets and shielding under the proton beam in the energy range 0.1 - 100 GeV the transport codes SHIELD [10] and RADDAM [11] are used. The SHIELD code is intended for statistical simulation of hadronic cascades in targets of arbitrary geometry and composition. Effects considered include transport of nucleons, antinucleons, pions, kaons and muons upto 100 GeV, ionization losses, straggling. The SHIELD's hadronic generator provides for exclusive description of nuclear reactions for all the energy and target nucleus mass ranges. As an example, the specific neutron leakage ($E < 10$ MeV) from the large lead target as a function of the incident proton energy is given in Fig. 1 [12].

Low-energy (below 10 MeV) neutron transport in optimization studies is simulated with the Monte Carlo code NeuMC [5].

3. Pulsed neutron source IN-06 ond possibilities of its development

The neutron source consists of the target irradiated with the proton beam accelerated by the linac and compressed in the storage ring and of the moderator system (Figs.2,3).

At the first stage, before the storage ring will be in operation, it is supposed to use the linac's proton beam with pulse duration 0.2-1 µs for nuclear physics studies and 30-150 µs for solid state physics studies. Pulse shaping is performed with the chopper in the linac's injector [13].

Presently, the accelerator is completely assembled and is capable of producing proton pulses with the energy 423 MeV, pulse current 20 mA, duration 0.2-70 µs and repetition rate 50 pps.

The bending magnets of the storage ring has already been manufactured. Mounting the magnet and vacuum systems of the storage ring is scheduled on the second half of 1997.

Initially the neutron source will operate with water-cooled tungsten and natural uranium silicide targets [4]. Rod fuel elements made of uranium silicide ($\gamma = 16.1$ g/cm^3) canned in stainless steel (1X18H9T - similar to 316 steel) tubes and distantiated with wire constitute a hexagonal lattice. 1.5-6 cm thick wing-type water moderators are placed above and below the target inside the vessel made of the Al-Mg alloy AMG-3 (Fig.4). Four neutron guides are directed at the upper moderator and three - at the lower one (Fig.5).

The tungsten target is assembled of 5-10 mm thick plates made of metal tungsten with density 18.9 g/cm^3 and coated with titanium.

Presently the most of neutron source construction is completed: cast-iron and heavy concrete shielding with netron channels and cavities for targets, collimators, choppers and gates; the targets and cooling circuit equipment are manufactured; the mounting is in progress.

Tungsten and uranium target elements have been tested in the core of the light-water research reactor.

Start of the source operation under the proton beam is scheduled late in 1996.

At the initial stage it is planned to conduct research works in the following directions:

- studying fission of heavy nuclei aligned at low temperatures (~0.1 K) with polarized resonant neutrons - collaboration of the Institute of Physical Energy (Obninsk), LNP JINR (Dubna), ITEP (Moscow), INR RAS;
- studying dynamics of solids and liquids using the inverse geometry spectrometer KDSOG - INR RAS in collaboration with LNP JINR [14];
- studying dynamics and structure of solids and liquids using the multifunctional spectrometer of Lebedev's Physical Institute RAS;
- properties of matter under high pressure - Institute of High-Pressure Physics RAS, Troitsk.

4. Multiplying targets

Further gain in slow neutron fluxes may be achieved by using multiplying targets [15]. High spallation neutron generation rate allows the deeply subcritical targets with the gain factor not exceeding 20 to be used. Even if the target will be surrounded by a thick reflector (upto 50 cm), prompt neutron lifetime in such a system will not exceed 100 ns [4, 5], and, as a consequence, power and fast neutron pulses will be 1.2 - 1.5 μs long.

The cumulative effect of neutron multiplication, comparatively soft spectrum of fission neutrons and slowing-down of neutrons due to elastic and inelastic scattering in a reflector results in achieving the peak and average values of slow neutron flux density as high as 10^{17} and 10^{14} n/cm^{2}s respectively [5]. The values given correspond to the 0.3 MW beam of 0.7 GeV protons. It is worth mentioning, that a neutron source using a non-multiplying target will require a 5 MW proton beam to achieve the same performance.

Preliminary study made by the INR RAS in collaboration with EDBMB (Nizhny Novgorod), Bochvar's ARSRIIM, RDIPE (Moscow), ARSRIEP (Arzamas-16) and IPE (Obninsk) has shown the possibility of creating a pulsed neutron source with such characteristics (project RIN-10). The source will have a multiplying target made of highly enriched U^{235} (U^{233},Pu^{239}) nitride and cooled with liquid gallium and will be driven with the proton beam of the MMF's linac compressed in the storage ring. The linac needs to be upgraded: the proton energy should be rised to 0.7 GeV and pulse duration - to 350 μs at the pulse current 50 mA.

The project requires the accelerator's equipment to be upgraded without any additional construction [2] and the new experimental hall with the target facility to be constructed (Fig.6).

Currently an intermediate design (RIN-3) is being considered which does not require neither accelerator's upgrading, nor any construction and can be implemented using the existing shielding and water cooling system (Figs. 7, 7a).

Some characteristics of the neutron source IN-06 for the first (1996-1998) and subsequent stages of its operation (storage ring, multiplying target) are given in Table 1.

5. Radiation studies

This year the construction of the beamstop with the core assembled of tungsten plates and cooled by water (Fig.8) should be finished. The existing system provides adequate cooling of the core and thermal shielding at the proton current upto 1 mA. The beamstop core has a channel for radiation studies of materials used under conditions of irradiation by protons and spallation, fusion and fission neutrons. The fast neutron flux density inside the channel as estimated by displacement rate will be about 10^{15} n/cm^{2}s at full proton current[16]. The energy spectrum can be estimated by the ratio of displacement rate to He production rate (Fig.9). Radiation studies are being prepared by collaboration of the INR, Kurchatov Institute, Bochvar's Institute of Inorganic Materials and R&D Institute for Power Engineering [17].

6. Lead slowing-down neutron spectrometry

Neutrons slowing down in lead tend to be phocused, at any given moment of time, in a comparatively narrow energy range with the half-width of 30-40 % of the average energy. This effect provides the possibility of the very sensitive neutron spectrometry in the energy range from thermal to 70 keV neutrons (with limited energy resolution).

Employing for generating the primary neutrons the spallation process induced by protons from the storage ring will allow the neutron source intensity as high as 10^{16} n/cm^{2}s to be achieved that is 8 orders of magnitude higher than that for the usual lead spectrometer based on the d-T reaction. This spectrometer will be capable of measuring actinide's fission cross sections for 10^{-12} g micro samples.

At present, the experiments are conducted on the small-scale prototype spectrometer "Python" (Fig.10) installed in the linac's tunnel on the direct proton beam. Proton pulses with the duration 0.2 μs and average current up to 1μA are shaped by a chopper in the linac's injector [13].

7. Applied studies

The following topics concerning the practical employment of the spallation process induced by ~1 GeV protons for transmutation of actinides and fission products are considered now:

- experimental studies based on the proton and H- beams of the MMF's proton linac and equipment of the neutron source IN-06 [8] concerning efficient utilization of plutonium in subcritical channel-type nuclear reactors (RBMK, Russia; CANDU, Canada);
- transmutation of long-lived fission products under proton irradiation [9].

8. Acknowledgements

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Pulse Neutron Source IN-06 / RIN-10

mode	f,pps	$\theta_P, \mu s$	$\theta_T, \mu s$	$\hat{\Phi}_T$ $\frac{neutr}{cm^2 s}$	$\bar{\Phi}_T$	W$_T$, MW	W$_{beam}$, MW
1. Accelerator,	50	40	50	3.2×10^{14}	0.8×10^{12}	0.08	0.06
U-target	50	150	160	4×10^{14}	3×10^{12}	0.3	0.22
2. Accelerator,	50	40	50	7.2×10^{15}	1.8×10^{13}	1.6	0.06
Multipl.target	25	150	160	7.7×10^{15}	2.9×10^{13}	3.3	0.11
3. Storage ring, U-target	50	0.35	30	2.1×10^{15}	3×10^{12}	0.3	0.22
4. Storage ring, Multipl.target	25	0.35 (1.2)	35	3.5×10^{16}	2.9×10^{13}	3.3	0.11
5. Upgrade ACC, SR, Mult.target	25	0.35 (1.2)	35	9.6×10^{16}	7.9×10^{13}	9.1	0.3

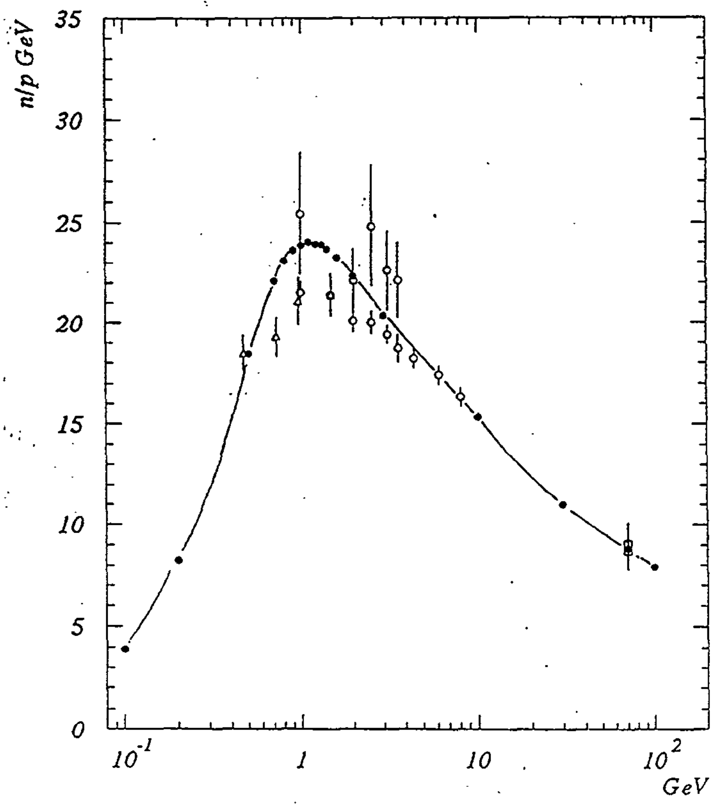
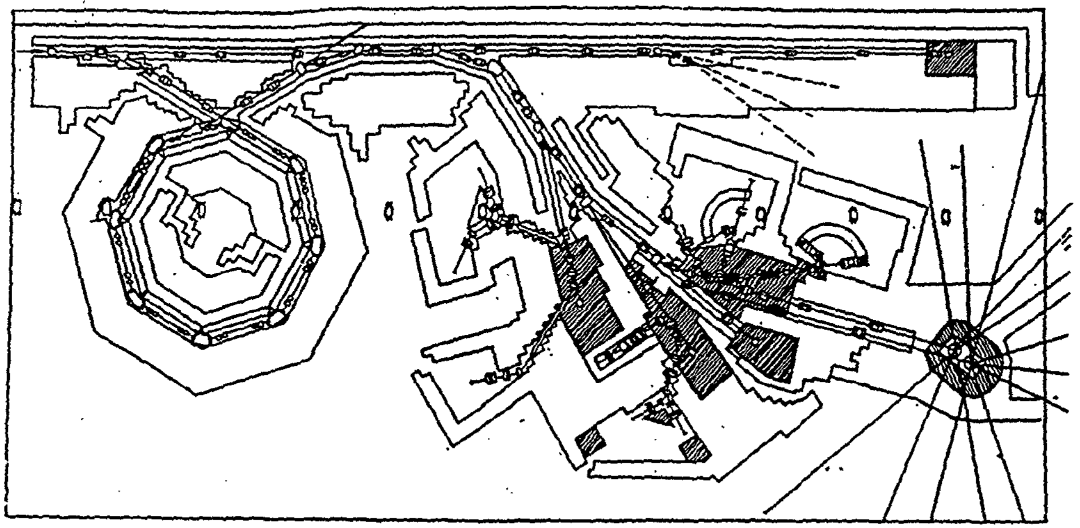


Figure 1: Yield of neutrons with energies below 10.5 MeV from total surface of cylindric lead target (D=20 cm, L=60 cm) in dependence on incident proton energy.



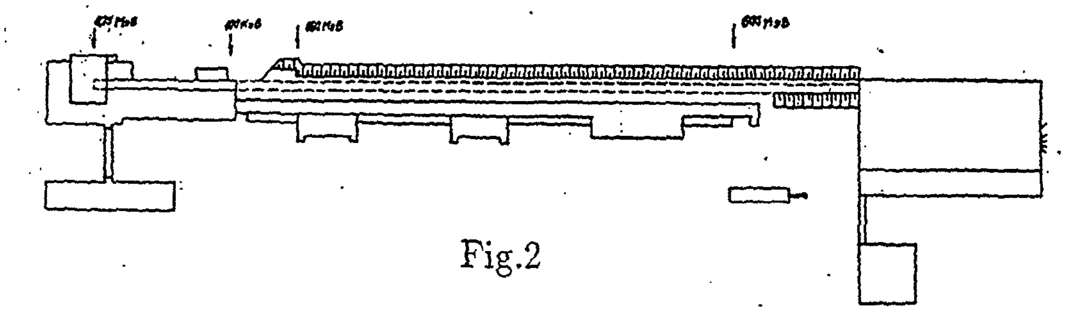


Fig.2

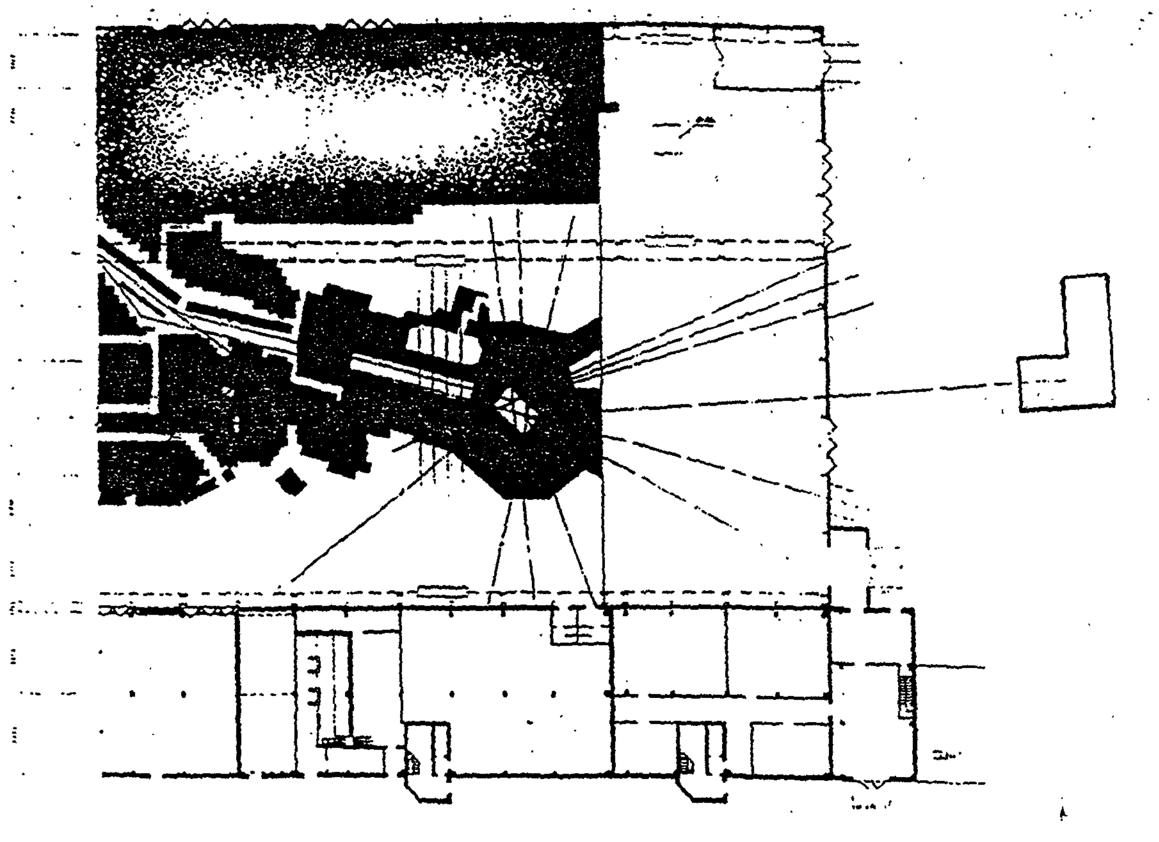


Fig.3

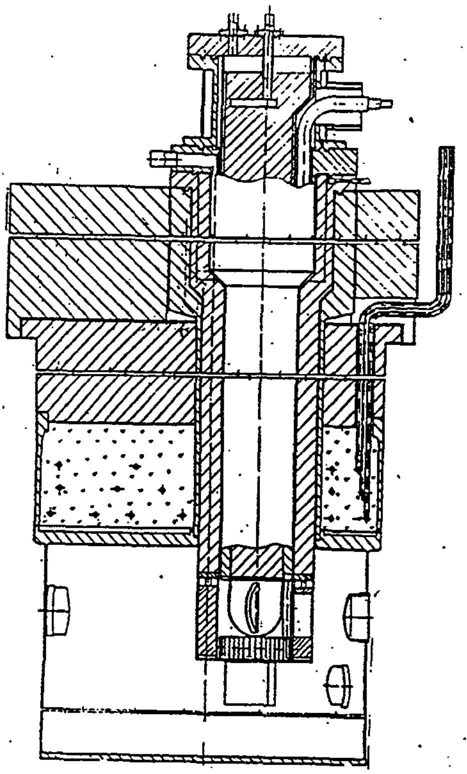
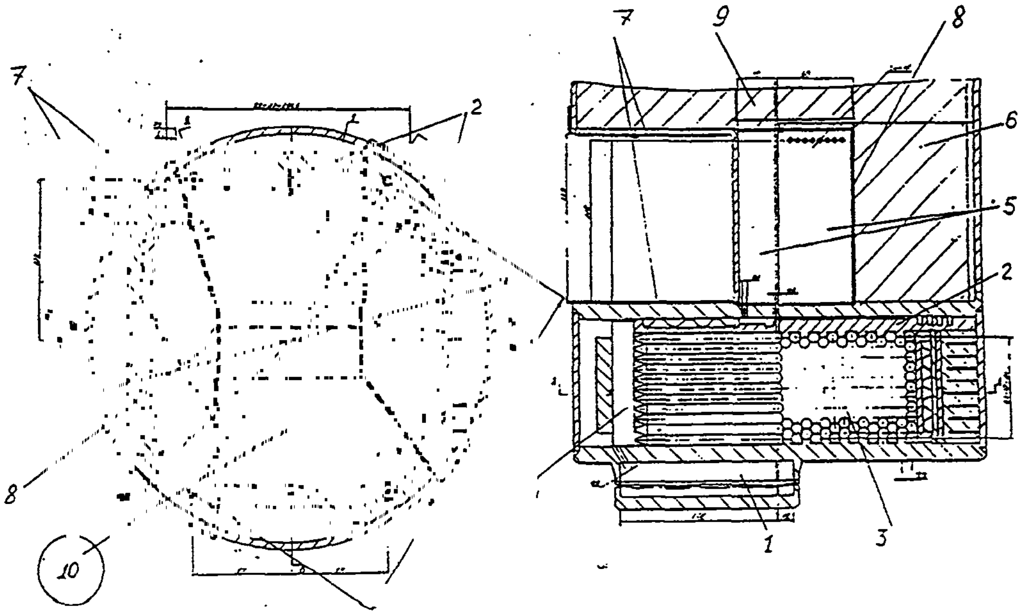


Fig.4



$^{238}USi_3$ target

1 - lower moderator; 2 - Ti-Gd decoupler; 3 - core; 4 - coolant inlet and outlet; 5 - upper moderator; 6 - reflector; 7 - Gd decoupler; 8 - Ti-Gd insertion; 9 - Be plug; 10 - fuel element.

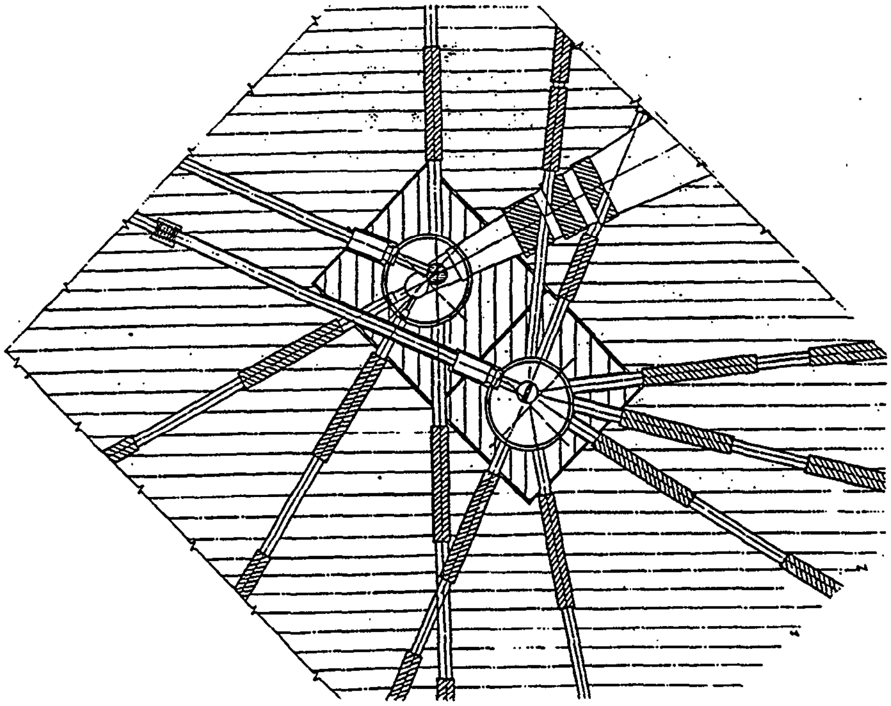


Fig.5

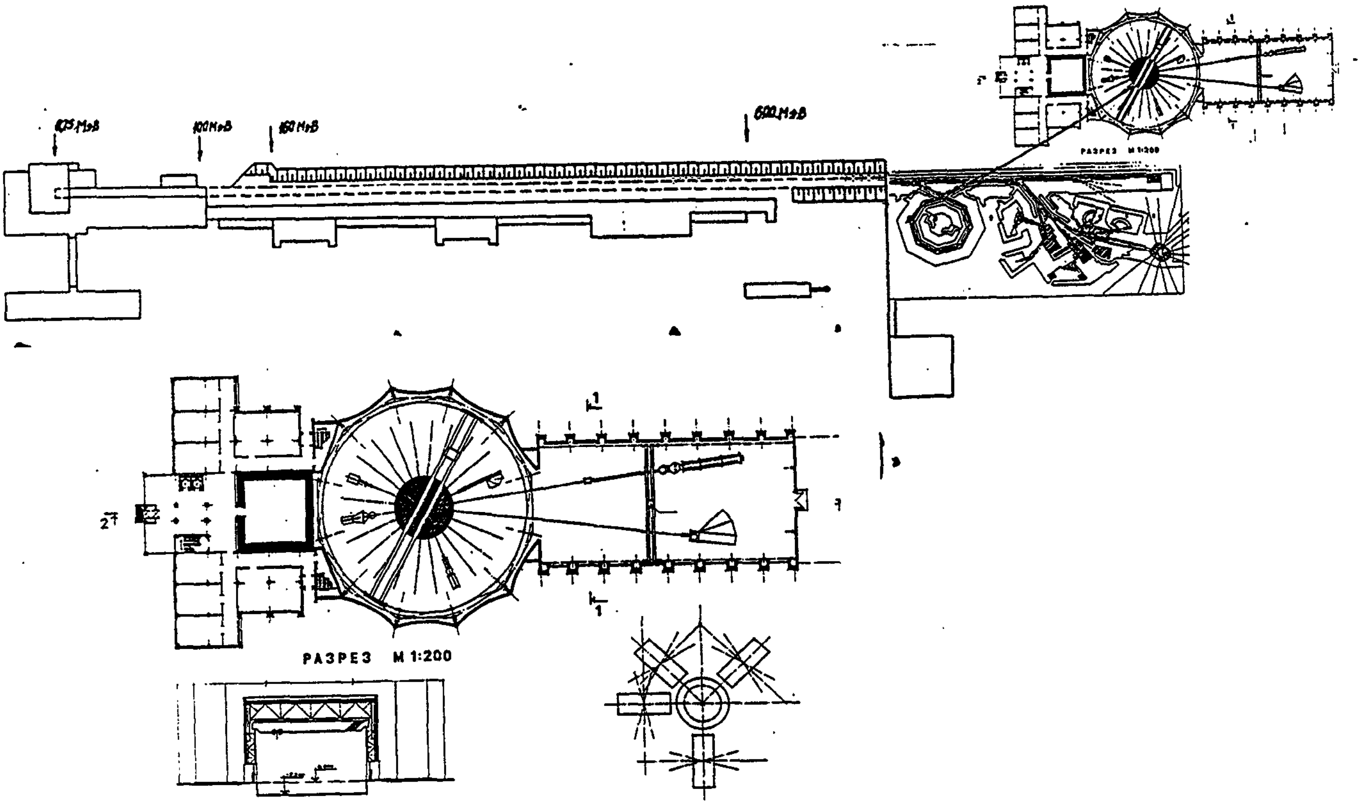


Fig.6

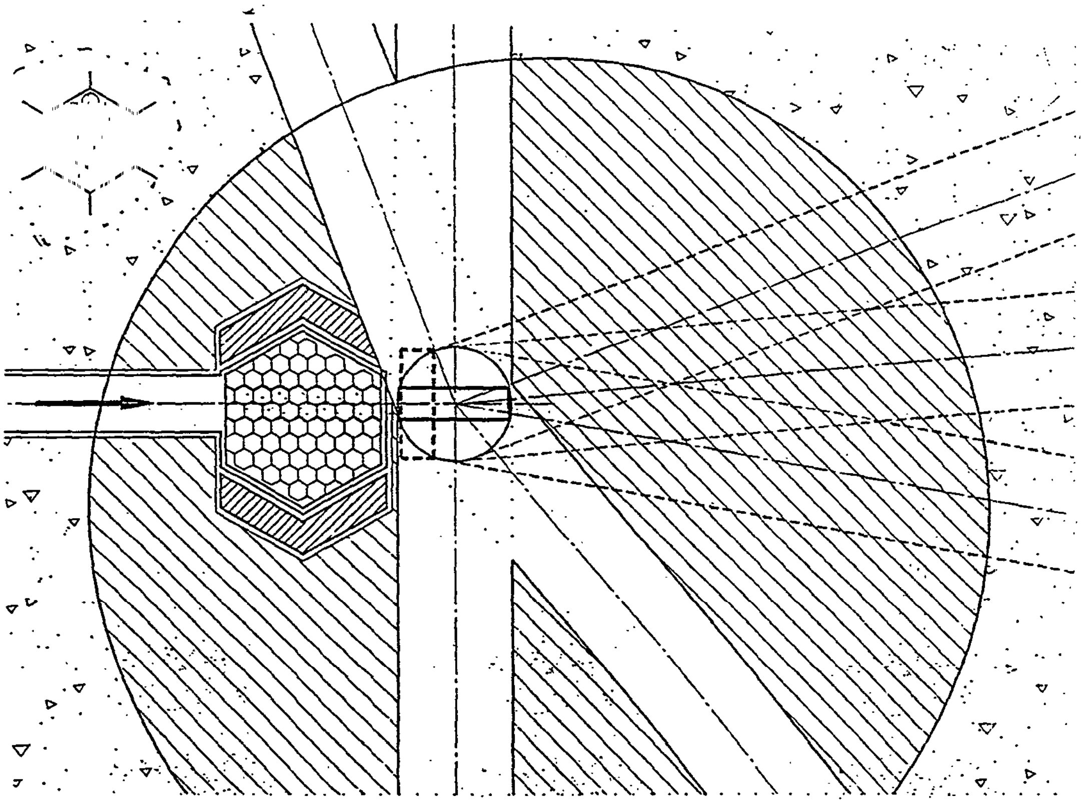


Fig.7

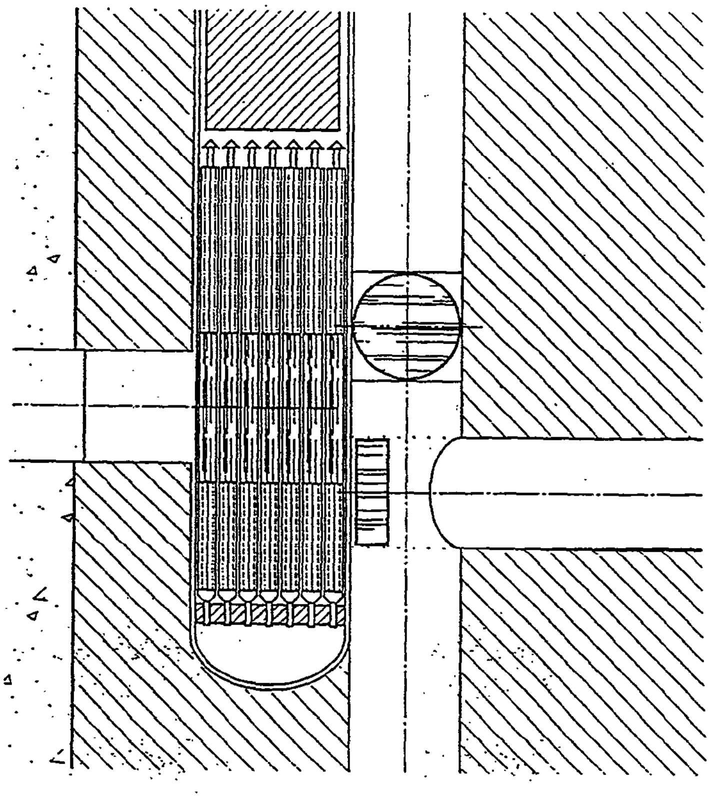


Fig.7a

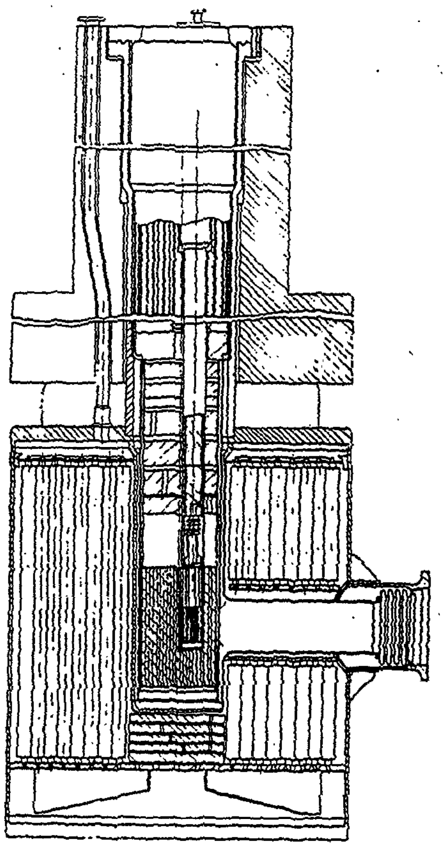
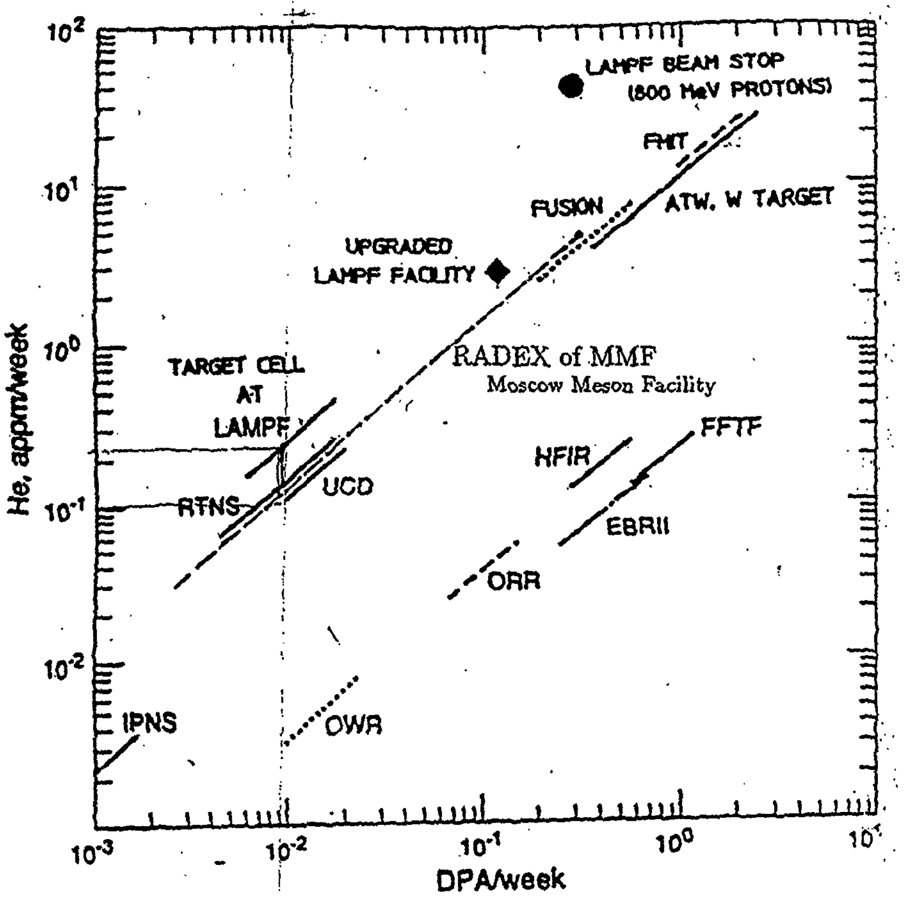


Fig.8



10²
10¹
10⁰
10⁻¹
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He, appm/week
10⁻³
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LAMPF BEAM STOP
(800 MeV PROTONS)
FMIT
FUSION
ATW, W TARGET
UPGRADED
LAMPF FACILITY
RADEX of MMF
Moscow Meson Facility
TARGET CELL
AT
LAMPF
RTNS
UCD
HFIR
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EBRII
ORR
IPNS
OWR

Fig.9

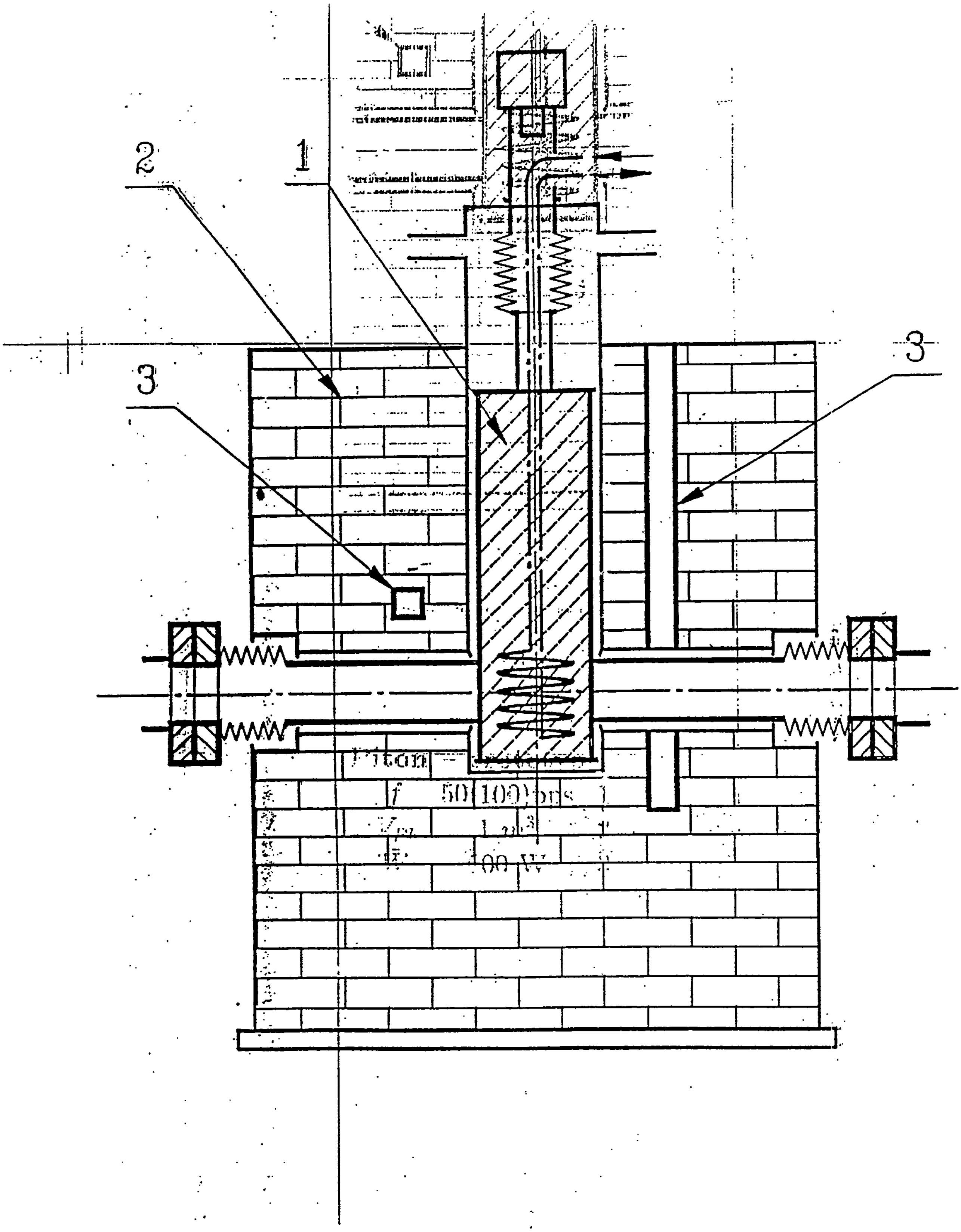

Fig.10 **Piton – prototype of SLS**

$\bar{J}$	$\sim 6 \times 10^{13}$	f	50(100)pps	1 – Target (Pb)
$\bar{i}_p$	$1\ \mu A$	V_{Pb}	$1\ m^3$	2 – Lead laying
θ_p	$0.2 \div 0.5 \mu sec$	$\bar{W}$	600 W	3 – experimental channels