PULSED NEUTRON SOURCE OF THE MOSCOW MESON FACTORY ON THE BASE OF URANIUM TARGETS

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The pulsed neutron source on the base of the high-current proton linac (average current $\simeq$ 0.5 - 1.0 mA, pulse width 100 to 00 μs and repetition rate up to 100 Hz) and proton storage ring (pulse width $\simeq$ of 0.32 μs, average current up to 0.4 mA, repetition rate 100 Hz) /1/ that is under construction at INR RAS will allow one to develop a wide range of research on condensed matter and nuclear physics.

A set of Ti-coated tungsten plates and close package of natural uranium rods in stainless steel cans placed into the Al-alloy vessel and cooled by light water are supposed to be used as neutron targets. The neutron facility is described in detail in /2-4/. Besides that, even at the initial stage of the experimental complex development, the use of the multiplying target with limited gain factor ($\leq$ 15) is possible. This will allow one:

- to increase significantly the average intensity of the pulsed neutron source at repetition rates 10 to 50 Hz, that is the most suitable range for TOF experiments;

- to decrease the beam current consumption down to 5-50% of the full accelerator intensity, thus making possible more experimental programs to be carried our concurrently;

- to limit the proton beam current in the storage ring (< 0.5 mA), that will make it easier to reach the required operational parameters and will increase its stability;

- to get the high performing neutron source at the initial stage of accelerator operation, before the design parameters will be achieved.

But the multiplying target has the background level much higher than that for non-fissionable targets. So the fissionable isotopes with low delayed neutron ration are preferable.

To create the multiplying target, besides changing natural uranium for highly-enriched fuel, one must decouple the core from moderators to prevent overheating or outer fuel elements by thermal neutrons and provide a short prompt-neutrons generation time /5, 6/.

It is expedient to use the identical design for both natural and enriched uranium targets to provide the full-scope elaboration of all elements of the multiplying target during the natural uranium target operation. It should be noted that existing design of the pulsed neutron source does not allow the transversal dimensions of the target core to be changed without replacing all the central part of the facility, including vacuum and target vessels and shielding plugs. Moreover, the layout of neutron guides inside the biological shield restricts the possibility to vary the core height within the range of 6 to 12 cm (Fig. 1). Therefore, to unify dimensions of the target vessel and reduce expenses, the transversal dimensions of the target could not exceed the adopted earlier diameter of 32.8 cm. Required gain factor could be achieved with changing the height of the target core and upper and lower moderators.

The part of neutron source, shown in Fig. 2, includes core, lower and upper moderators, and Be reflector surrounding the upper moderator /5, 6/.

The target core consists of fuel rods made of sub-stoichiometric U_3Si in stainless steel cans which are 8 mm in diameter and 0.3 mm thick. This fuel composition has the density of 16.1 g/cm^3 and contains 15.8 g/cm^3 of uranium, that is comparable with U-Mo metal alloys (Fig. 3). In case of cladding failure the fuel composition corrosion rate is small enough: less than 0.02 mg/cm^{2}h at 100C and 0.07 mg/cm^{2}h at 200°C. This fuel composition in cylindrical cans promotes good swelling resistance and allows the burn-up of 2 at.% to be achieved, which is very important taking into account the high cost of highly-enriched uranium. The adopted core dsign prevents blocking of coolant channels, which is possible for the scheme with disk fuel elements, and provides the normal target operation for 3 to 5 years. Besides that, U_3Si composition easily changes its state to amorphous and provides good thermal contact between the fuel and can after several tens hours of operation at nominal power. This thermal contact was preserved under conditions of shutdowns and raising the power during reactor tests. The presence of amorphous layer decreases influence of the thermal impact on the fuel element cladding. In the most stressed case (target on the base of $^{233}U_3Si$ enriched to 98%) the fuel temperature raises up to 15 - 18°C per pulse. To decrease the axial thermal stresses the fuel rod is split into 3 parts. The available technology enables both natural and enriched uranium fuel elements to be manufactured. Prototypes of fuel elements were tested in nuclear reactors for 3.5 years and the burn-up of 3 at.% has been achieved.

The main disadvantage of the cylindrical fuel elements as compared to the slab ones is the decrease in the fuel volume fraction that leads to decrease in a number of spallation neutrons per incident proton - K_n. The computed conversion coefficient K_n and multiplication factor K_m as the functions of the core height are shown in Fig 3. As it can be seen, the use of U_3Si rods instead of tungsten plates of height 6 cm increases th spallation neutron production by a factor of 1.4, while these values for pure uranium and tungsten targets differ by a factor of 1.7÷2.0/10/. This makes us consider the natural uranium target only as an intermediate step toward the highly enriched uranium target with a multiplication factor of 2 to 10. Multiplication factor is limited by the following requirements: low delayed neutrons background nuclear safety requirements for subcritical assemblies without control and safety systems /10/, and, finally, coolant system capacity (2.5 MW). On the other hand, our intent is to construct the thermally stressed target, which provides the total neutron production per proton not less than that for pure uranium and one whose operational lifetime is long enough.

In order to provide the uniform cooling and not to lengthen the fast neutron pulse due to the slowed-down neutrons induced fission, both the coolant inlet and outlet are made as vertical slots in a plate made of material well absorbing epithermal and thermal neutrons. The most suitable materials, compatible with other materials of the target, are hafnium, zirconium-hafnium and titanium-gadolinium alloys with the addition of rare-earth elements. The plate made of the same alloy is placed on top of the core, while the lower side of the target vessel is coated by the thin layer of the absorber.

The use of different metals and allkoys required extensive studies of their compatibility and providing of water conditions. Data on corrosion rate of possible target materials in distilled water at various conditions (including neutron irradiation) are given in Fig. 4. For additional protection against corrosion all aluminium parts of the target are coated by titanium. Reactor tests of A1 and W samples in water have shown that Ti coating is stable and compatible with other core materials. No changs of Ti coating were observed after the priod of time comparable with that of the target operation.

The fuel elements are distantiated by stainless-steel wire of 0.4 mm thickness. To recompense for thermal expansion and to avoid vibrations due to collant flow, the fuel elements assembly is embraced by the spring elements made of Zr-Mo alloy. This alloy preserves its elasticity under irradiation and is compatible with target materials.

The upper moderator is surrounded by the berillium reflector cooled by water flowing to and from the target core. The outer part of the target vessel is coated with Gd, which acts as a decoupler for upper moderator and, at the same time, provides nuclear safety in case of accidental flooding of the vacuum vessel with water. This decision allows one to provide the satisfactory thermal contact of an absorber and construstruction material and to escape the need of additional studies of material compatibility in the water.

The upper moderator has face dimension of 12 x 12 cm^2 and thickness of 5.5 cm. To shorten the thermal neutron pulse width the moderator is split with Ti-Gd plate into two parts - say, 2 and 3.5 cm. This allows the moderator to be customised for particular experiments. The lower moderator has dimensions of 20 x 20 x 3 cm^3 and is optimised for experiments with intermediate and epithermal neutrons.

Parameters of pulsed neutron sources based on the W, U^{238}, U^{235} and U^{233}, with the storage ring are compared in Table 1. It can be seen that the multiplying target has the thermal neutron flux density 6 times higher than the natural uranium one.

At present, natural uranium fuel elements, Be reflector, A1 target vessel, and shielding plug are manufactured. Tests on compatibility and corrosion rates of target materials are completed. Now we are finishing manufacturing the parts made of Ti-Gd and Zr-Mo alloys and coating target core parts with Ti. In the next year we plan to complete assembly, certification and coating the target with Gd.

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TABLE 1.

Target parameters	W	U^{238}	U^{235}	U^{233}
Average power, MW	0.2	0.4	2.12	2.17
Background power, MW	-	0.004	0.014	0.0063
Thermal neutrons pulse width, mks*	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/cm²s*	$3.0 \cdot 10^{12}$	$4.0 \cdot 10^{12}$	$10.6 \cdot 10^{12}$	$18.1 \cdot 10^{12}$
Peak thermal neutron flux density,n/cm²s*	$1.0 \cdot 10^{15}$	$1.3 \cdot 10^{15}$	$11.8 \cdot 10^{15}$	$20.1 \cdot 10^{15}$
Repetition rate, pps	100	100	30	30

*For 3.5 cm part of water moderator.

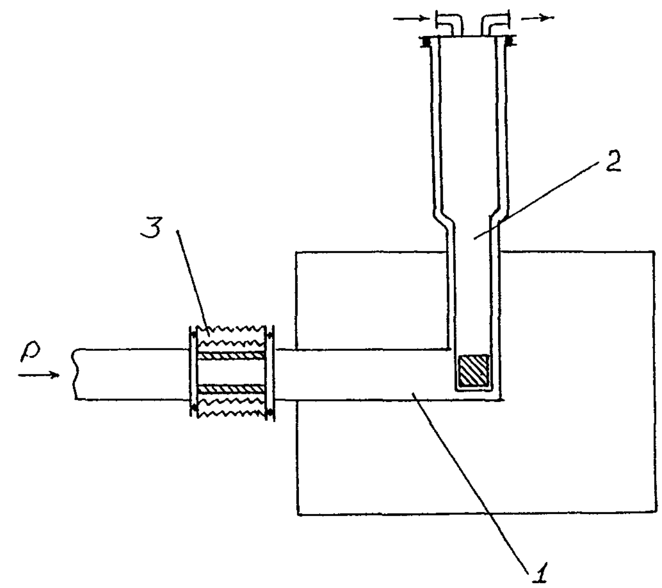

Fig. 1 Design of neutron source.

1 - Tank with vacuum system; 2. - Ampoule of source,

3 - Remote-controlled vacuum seal.

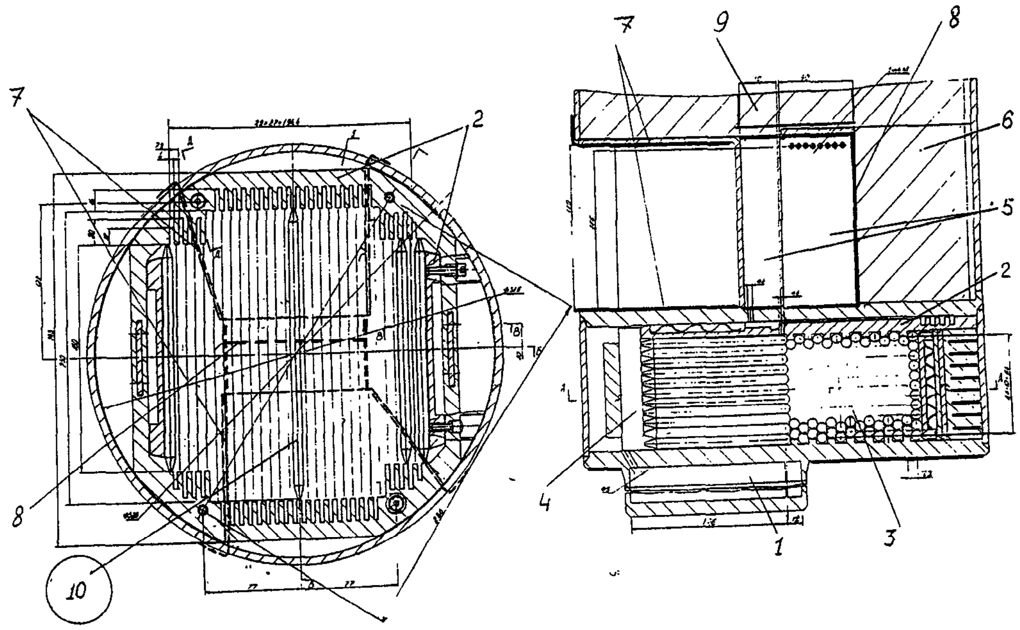

Fig. 2a. Central part of the multiplying neutron source.

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.

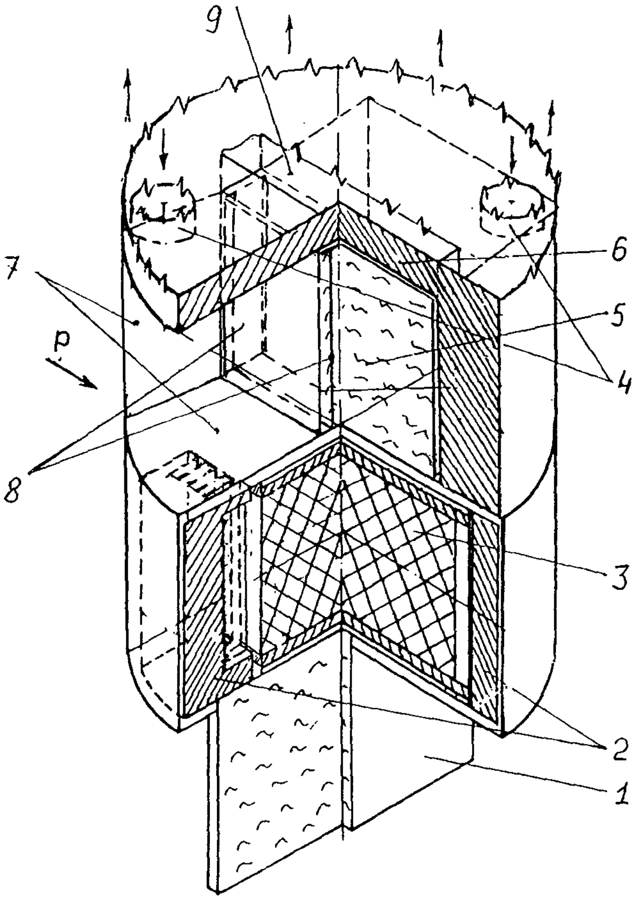

Fig. 2b. Central part of the multiplying neutron source.

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.

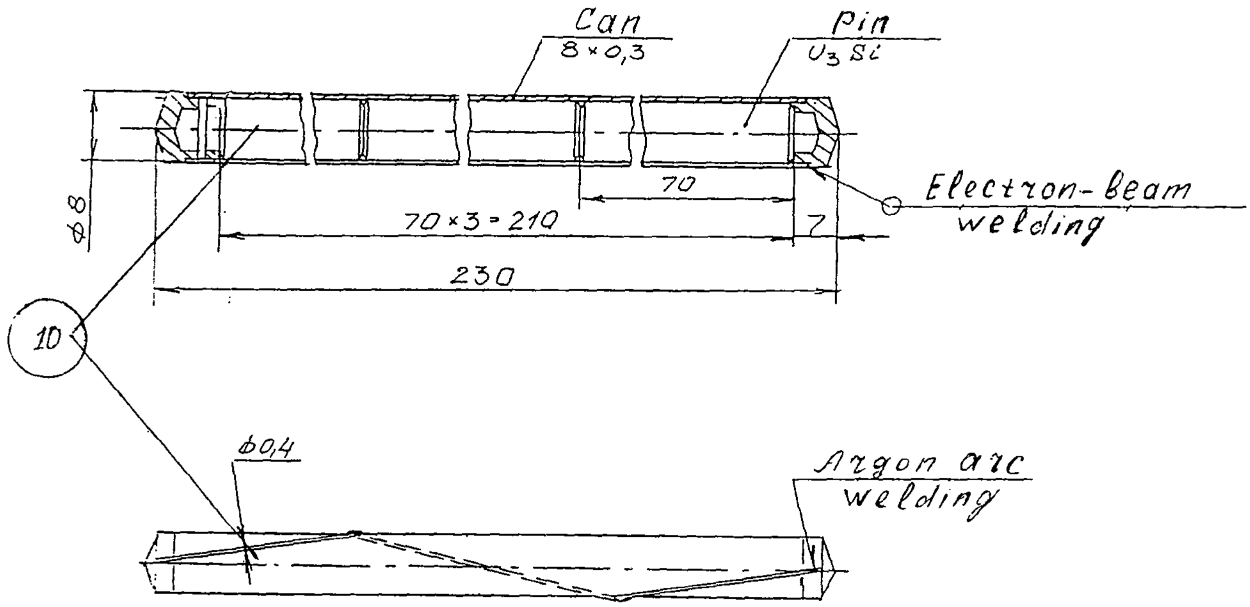

Fig. 2c. Fuel element

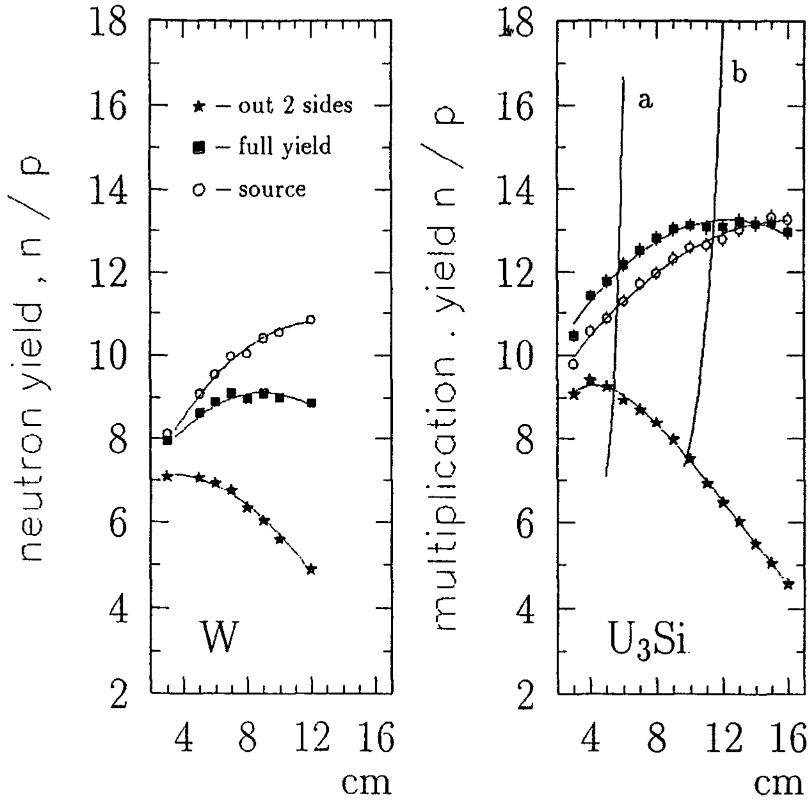

Fig. 3. Computed spallation neutron yield per 600 MeV incident proton for tungsten (1) and natural U3Si (2) targets and multiplication factor for U235 (b) and U233 (a) targets as the functions of the core height.

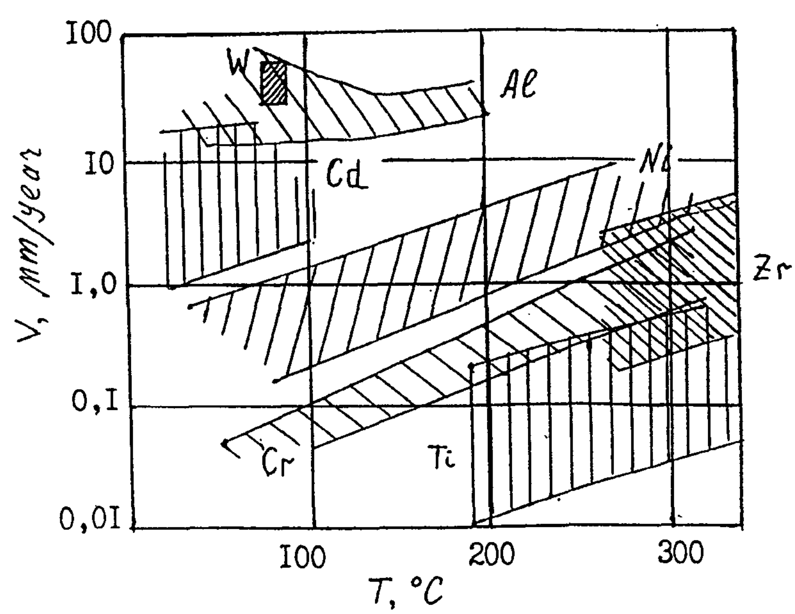

Fig. 4. Corrosion rates of possible target materials in distilled water at various conditions.