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Multiplicating neutron targets based on the proton beam of Moscow Meson Facility.

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ABSTRACT

The main physical parameters of the pulsed neutron source with limited multiplication ($\leqslant$ 10) based on the proton beam of the Moscow meson facility are discussed. The results of calculation of an optimal multiplication coefficient are presented.

One way to increase the intensity of pulse neutron sources based on the high-current proton beams and used for time-of-flight experiments is connected with the use of multiplicating targets/3/. This gives the following possibilities:

a) to increase by several times the intensity of the pulse neutron source in the frequency range 10-30 Hz, which is the most convenient for most time-of-flight experiments;

b) to reduce the used proton beam current to 5-30% of the full accelerator intensity that allows a number of the various experiments to be carried out concurrently;

c) to provide high performance of the neutron source in the early stage of the accelerator operation when the full beam intensity will not yet be obtained.

However, multiplicating targets have greater fast neutrons pulse duration and background level between pulses comparing to non-multiplicating ones.

The optimal multiplication factor as a function of mean lifetime of prompt fission neutrons τ and energy E of neutrons used in time-of-flight experiments is shown in Fig. 1 /4/. Drawing this plot it was assumed that protons are ejected from the storage-ring-compressor with pulse duration T_s = 0.32 µs /5/. The multiplication factor K_M increases with decrease of τ and increase of the dispersion of time of slowing down of fast core neutrons to energy E and length of the diffusion in the external moderator $\tau_M(E)$, reaching its maximum value in the thermal neutrons range/4/. To determine K_M and compare pulse sources the figures of merit united into two groups were used:

$$K_{1n} = \overline{\Phi} / \theta^n, \qquad K_{2n} = \overline{\Phi S} / \theta^n,$$

where n - order of figure of merit ($1 \leqslant n \leqslant 4$),

$\overline{\Phi}$ - mean flux density of neutrons with the energy E on the radiating moderator surface, S - area of the moderator surface that is visible from the sample side,

$\theta = \sqrt{\tau_M^2(E) + \theta_{eff}^2}$ - efficient neutron pulse duration,

θ_{eff} - efficient core neutron pulse duration /6,7/.

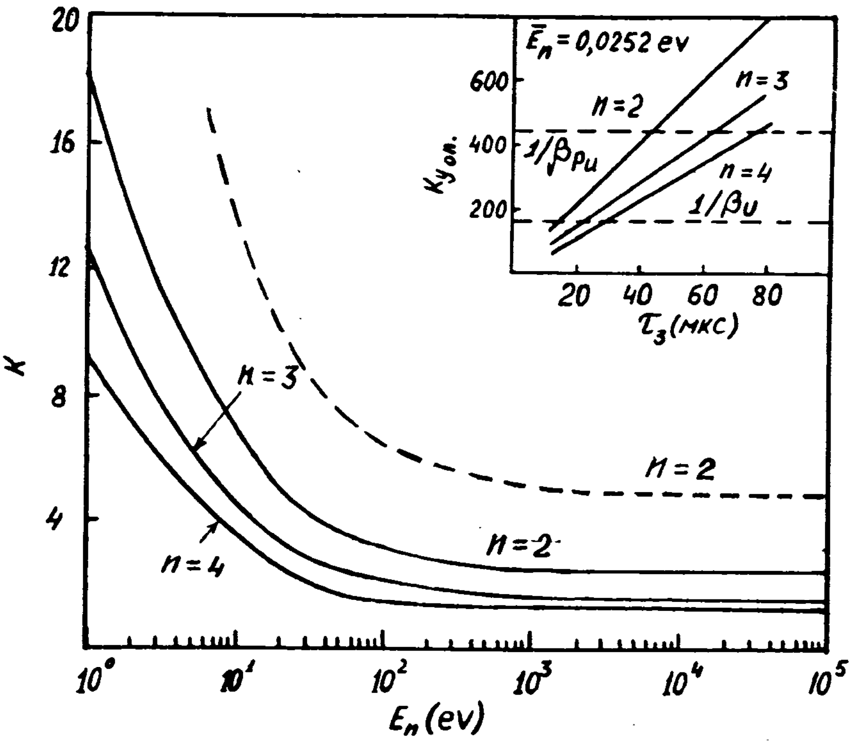

Fig. 1. Main plot: Optimal multiplication coefficient as a function of neutron energy required in an experiment for two values of prompt neutron life-time in case of using the proton beam compressor with pulse duration $T_s = 0.32$ μs.

Insertion: Optimal multiplication coefficient as a function of neutron moderation time spread. The dashed lines mark the lower boundary of the region where the reactivity modulator is needed for U and Pu.

On the first stage of experimental complex development it is possible to use targets with limited multiplication ($K_M \leqslant 15$) replacing depleted or natural uranium by highly enriched fuel and not changing the overall neutron source design /1/. This decision requires decoupling of target core and moderators to prevent increasing of pulse duration and overheating of outer core elements by thermal neutrons produced in external moderators. Design performance of the pulse neutron source with limited multiplication with core elements made of U^{233} or U^{235} alloys and ceramics operating at 25 Hz is presented in Table 1. The can of a fuel element made of stainless steel is capable to provide fuel burn-up up to 2% or 2.5 years of continuous facility operation. Proton beam consumption constitutes 25% of a full accelerator intensity if the storage-ring-compressor is used to produce short proton pulses, and 5% - if accelerator pulses are simply "cutted" to 20 μs. It can be seen that the thermal neutrons flux density increases by a factor 6-7 as compared with the U^{238}-target.

Table 1.

Target parameters	^{235}U	^{233}U	^{238}U
Average power, MW	2.5	2.5	0.15
Background power, MW	0.0175	0.0075	0.0028
Thermal netrons pulse duration и θ_T, μs	35	35	35
Multiplication K_M	10	10	—
Average thermal neutrons flux density - $\overline{\Phi}_T$, n/cm^{2}s	$2.7*10^{13}$	$3.6*10^{13}$	$4.3*10^{12}$
Peak thermal neutrons flux density Φ_{peak}, n/cm^{2}s	$3.1*10^{16}$	$4.1*10^{16}$	$4.9*10^{15}$
Pulse frequency (with storage ring), Hz	25	25	25
$\overline{\Phi}_T/\theta_T^2$ *	17	17	17
I_{cold}**, n/s	$6.8*10^{15}$	$8.3*10^{15}$	$1.1*10^{15}$

*) As compared with design performance of the pulse reactor IBR-2 /8/.

**) For the quasistationary source of thermal and cold neutrons.

To evaluate optimal design parameters of the multiplicating target that provide minimum core dimensions, required multiplication factor (~ 15), and satisfactory cooling conditions (maximum fuel temperature ≤ 500°C for U-Mo-alloy and maximum temperature of the outer surface of the fuel element ≤ 120°C) the Monte-Carlo code MCU was used /11/. The target design used in computations is presented in Fig. 2. Optimal design parameters determined for the target with thermal power 2.5 MW is presented in Table 2. It should be noted that to provide fuel-coolant compatibility in a wide temperature range in case of a fuel element can destruction U_3Si - ceramics and U-Mo(9%)-alloy were considered as the fuel composition for the light-water and PbBi-eutectic coolant correspondingly.

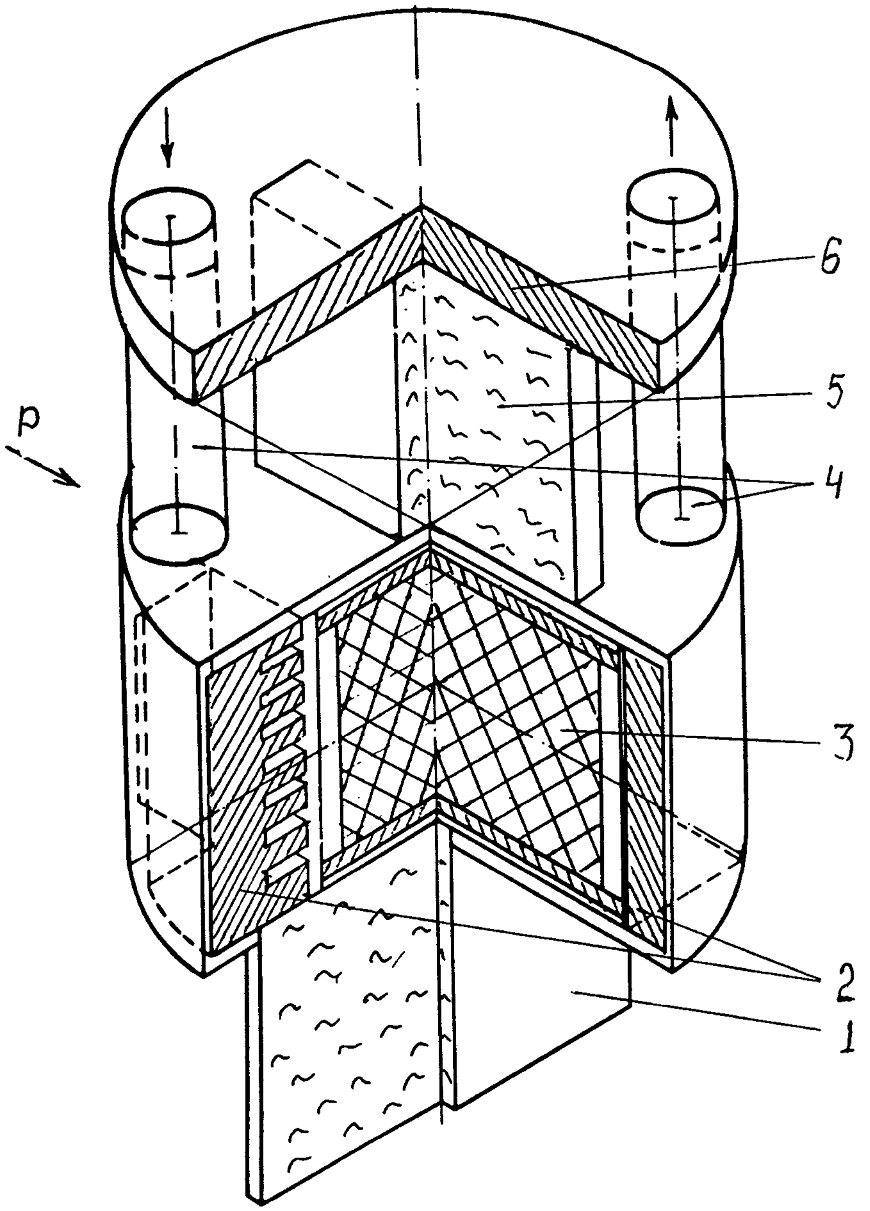

Fig. 2. Calculational scheme of the multiplicating target:
1 - lower moderator
2 - decoupler
3 - core
4 - coolant's inlet and outlet
5 - upper moderator
6 - fragment of the moderator's reflector

Table 2.

Core parameters *	^{235}U + Mo(9%)	^{233}U + Mo(9%)	Coolant
Dimensions, cm	13.2*15*22.7 (16.4*16*22.7)	7.6*15*22.7 (10*15*22.7)	H_2O (Pb-Bi)
Fuel element diameter, mm	8.5 (7.9)	6.3 (5.8)	
Maximum fuel temperature, °C	504 (505)	504 (504)	
Maximum fuel element surface temperature, °C	117 (321)	117 (314)	
Fuel content, vol.%	69.6 (68.3)	64.0 (62.3)	

*) With the tungsten reflector.

The more flat target core based on U^{233} and cooled by H_2O is the most efficient since it provides both the lowest background level and the highest neutron leakage out of the core into external moderators. Besides its dimensions are close enough to the yet designed U^{238}-target ones (6*15*22.7 cm^3) that allows neutron guides through the biological shield to be used without any changes /1/.

It should be noted that unlike the U^{238}-target the multiplicating target can not be used as the beam dump cause if the full accelerator beam is directed onto the target its thermal power will be 7 MW that exceeds the design heat release almost by a factor of three. This causes the stronger requirements to control system reliability to prevent directing of the full accelerator beam onto the multiplicating target.

Possible performance of the target with high multiplication (~ 100) was considered in detail in the paper /3/. Using this target the peak flux density of thermal neutrons on the radiating moderator surface as high as $2*10^{17}$ n/cm^2s can be obtained.

Yet another field of application of the multiplicating target is considered in detail in the paper /10/.

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