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Measurement of the Neutron Yield from Tungsten Target Irradiated with 70-GeV Protons.

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1. Introduction

In present time in a number of laboratories (LAMF, TRIUMF, KEK, Institute for Nuclear Research) the projects of the high current proton synchrotrons for the energies of tens GeV (kaon facilities) are under development. As it was shown earlier in the papers [1,2] high current proton accelerators of intermediate and high energy protons are the good base to construct high intensity neutron sources since significant growth of neutron yield from thick targets should take place when the energy of incident proton increases. Since the available suggestions on the construction of these neutron sources have been based on the theoretical estimates of the neutron yield it is interesting to detect directly on experiment the evaporated neutron yield from the targets irradiated with accelerated protons.

2. Experimental Scheme.

The yield of neutrons from tungsten target irradiated with 70-GeV protons on Serpukhov accelerator was measured in the present work. The target was assembled of tungsten plates of the sizes 160x160x300 mm.

The measurements were carried out on the 23 canal (intensity about 10^{10} p/pulse) and on the 21 canal (intensity about 10^{5} p/pulse).

In the first case the proton beam coming on the height of 1350 mm from the concrete floor was being detected by means of the copper foil placed before the target. The positions of the proton beam before and behind the target were determined by means of the photographic paper in the experiment without the target.

In the Figure 1 the experimental scheme, the final proton beam position and its sizes before the target are given.

To detect neutrons from the target the indium foils were used on the 23 canal. These foils were placed into the polyethylene balls of 127 mm diameter being in the cadmium cover on the distance of 750 mm from the geometrical target center at the angles 45^{0}, 0^{0} and

-22.5^0(Fig. 1). In the Figure 2 the function of the sensitivity of these ball detectors is presented.

To find neutron flux distribution on the target surface the assembly of the activation detectors made with the plastic scintillator, rhodium foils and phosphorus in the single cadmium cover and the aluminum foil was used. The basic characteristics of the detectors are given in Table 1.

Table 1.

Main characteristics of the activation detectors

Det.	Reaction	Cross Section (mbarns)	Thresh. (MeV)	Size (mm)	Density (g/cm^3)	$T_{1/2}$	Ref
Cu	$Cu(p,spa)Na^{24}$	3.90	2000	d110x0.1	8.93	15h	5
CH_2	$C^{12}(x,xn)C^{11}$	22	20	d20x9	1.06	20.4m	4
Al	$Al^{27}(n,\alpha)Na^{24}$	30	6	d40x6	2.70	15h	4
P	$P^{31}(n,p)Si^{31}$	124	2.2	d20x3	2.20	2.62h	6
Rh	$Rh^{103}(n,n')Rh^{103m}$	1000	1.0	d15x0.1	12.44	56.12m	6
In	$In^{115}(n,\gamma)In^{116m}$	160000	0	d30x0.12	7.3	5.4m	4

The verification of the aluminum and copper detectors was carried out with the single crystal scintillation gamma-spectrometer (NaJ(Tl) d150x100) on the line of $E\gamma$ =2.75 MeV.

Also the verification of the phosphorus and carbon detectors was done with the low background radiometric set (the polyester crystal of the size d45x50 mm with the photomultiplier of FEU-82 type) [7]. The rhodium detectors were verified with the semiconductor gamma-spectrometer of the DGR5 type meant for low energy Rontgen and gamma radiation. The radionuclide Rh^{103m} produced in the reaction of inelastic scattering $Rh^{103}(n,n')Rh^{103m}$ and having the half-life period $T_{1/2}$= 56.12 min was being detected on the line of $E\gamma$= 20 keV. The yield of gamma quanta of this energy is 7.865% per decay [8]. The effectiveness of the gamma quantum detection was determined with the model source Am^{241} on its line E = 25 keV. To suppress the contribution of the reaction $Rh^{103}(n,\gamma)Rh^{104m}$ ($T_{1/2}$ = 4.4 min) the foil was placed in the cadmium screen and kept there for about 1 hour after irradiation.

Calibrating measurements were carried out with Cf^{252} on the same geometry when four central plates of 10 mm thickness had been replaced by the steel plate of 40 mm thickness with the cell for the source in the center. The source was being placed both in the target center ("O") and on the side ("A") (Fig. 1).

In the measurements on the canal 21 the proton beam, which was on the height of 2250 mm from the concrete floor was being detected by two scintillation counters of 100 mm diameter with the effectiveness of the charged particle detection higher than 99.9%. The coincidence of the data of the counters was a "trigger" of the set and simultaneously gave the number of protons incoming on the target. Two additional counters in the form of the perpendicular scintillating rods of the sizes 2x2x100 mm were used for the precise beam directing on the target center.

For the detection of neutrons from the target the neutron detector on the basis of the gas-discharge counter STS-6 enveloped by the rhodium foil was used in the 21 canal. The counter was placed into the polyethylene sphere of the diameter 254 mm. To decrease the influence of interferences and background radiation the set of detection was under operation during 2 seconds between accelerator cycles of 9.7s duration one second after the proton pulse of 0.7s duration. Since the half-life period of the basic line of Rh^{104} $T_{1/2}$= 44 s the correction caused by the relative pulse duration is equal to k= 4.50. The detector was placed at the angle 90^{o} to the beam axis on the distance of 1.5 m from the axis.Calibrating measurements were carried out with Cf^{252} when the geometry was the same.

3. Results of Measurements.

23 canal.

The results of measurements on the 23 canal when the number of protons for the exposition was $8.54*10^{14}$ +- 5% for the time of 30 min are given in Table 2. Here the neutron fluencies from Cf^{252} per one neutron of the source are are also presented.

Table 2.

Source	Protons			Cf^{252}("O")			Cf^{252}("A")		
Position	45	0	22.5	45	0	-22.5	45	0	-22.5
Neutron Fluency $\frac{n}{cm^2*p(n)}*10^5$	1500	1600	1400	2.6	3.1	2.7	4.7	2.4	1.9

As it follows from the data of the table the angular dependence of the neutron flux around the target irradiated by protons has a little difference from the corresponding dependence for the target with the point source in the center. Taking into account the weak dependence of the neutron detector sensitivity on the neutron spectrum we obtain the following neutron yield from the target per one incident proton: Y= 514 $^{n}/_{p}$ +- 11%. In Figure 3 the distribution of the neutron flux on the target surface is presented.

21 canal.

Table 3 shows the results of measurements on the 21 canal.

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Table 3.

Run	Presence of target	Number of protons in 21 canal, $N_p *10^5$	Detector Counts N_n	N_n/N_p 10^5	Number of protons in 8 canal 10^{14}
1	-	1.28	3885	30.4	4.19
2	W	1.07	21136	197	3.52
3	-	1.65	2376	14.4	3.08
4	W	2.19	59797	273	8.70
5*	W	1.23	278	2.3	3.19

* Measurement without Rh-foil in neutron detector

In using the neutron detector on the basis of the gas-discharge counter enveloped by the Rh-foil it is necessary to take into account the neutron and gamma background. To determine the background measurements were carried out without the target when the proton beam was going past of the set to the beam stop. In this case neutrons and gamma radiation from the protection were being detected. Measuring with the tungsten target but without Rh-foil in the detector gave the contribution of all gamma radiation. Without Rh-foil and the target we have the contribution of the gamma radiation coming from the protection only. Comparing the results of the measurements #5 with those of #1 and #3 shows that the neutron contribution is about ten times as large as that of gamma radiation. According to Table 3 there is the correlation between the value of the background and the current in the canal 8. Taking into account this correlation we can obtain the average rate of the detection S= $1.94*10^{-3}$ per an incident proton. The background is 12% in the first measurement with the W-target and 22% in the second one.

The measurements when Cf^{252} (intensity $7.4*10^7$ $^n/s$) is in the center of the target (5% error with the credible probability 0.95) and the geometry is the same gave the following numbers of scintillations for 60 seconds : 82480 with the Rh-foil and 8278 without the foil. In account of the relative pulse duration given above, as well as the measured value S, we shall obtain the neutron yield from the W-target : Y_{21}= 533 $^n/_p$ +- 12%.

Conclusions.

The measurements carried out on the 23 and 21 canals gave the close values of the neutron yield from tungsten target. The average value of the yield is Y= 524 $^n/_p$. This value is two times less as neutron yield calculated by means of the linear dependence based on the experimental data for energies E_p< 1 GeV [9]. Using of the more thick target will give larger neutron yield as compared to the measured one.

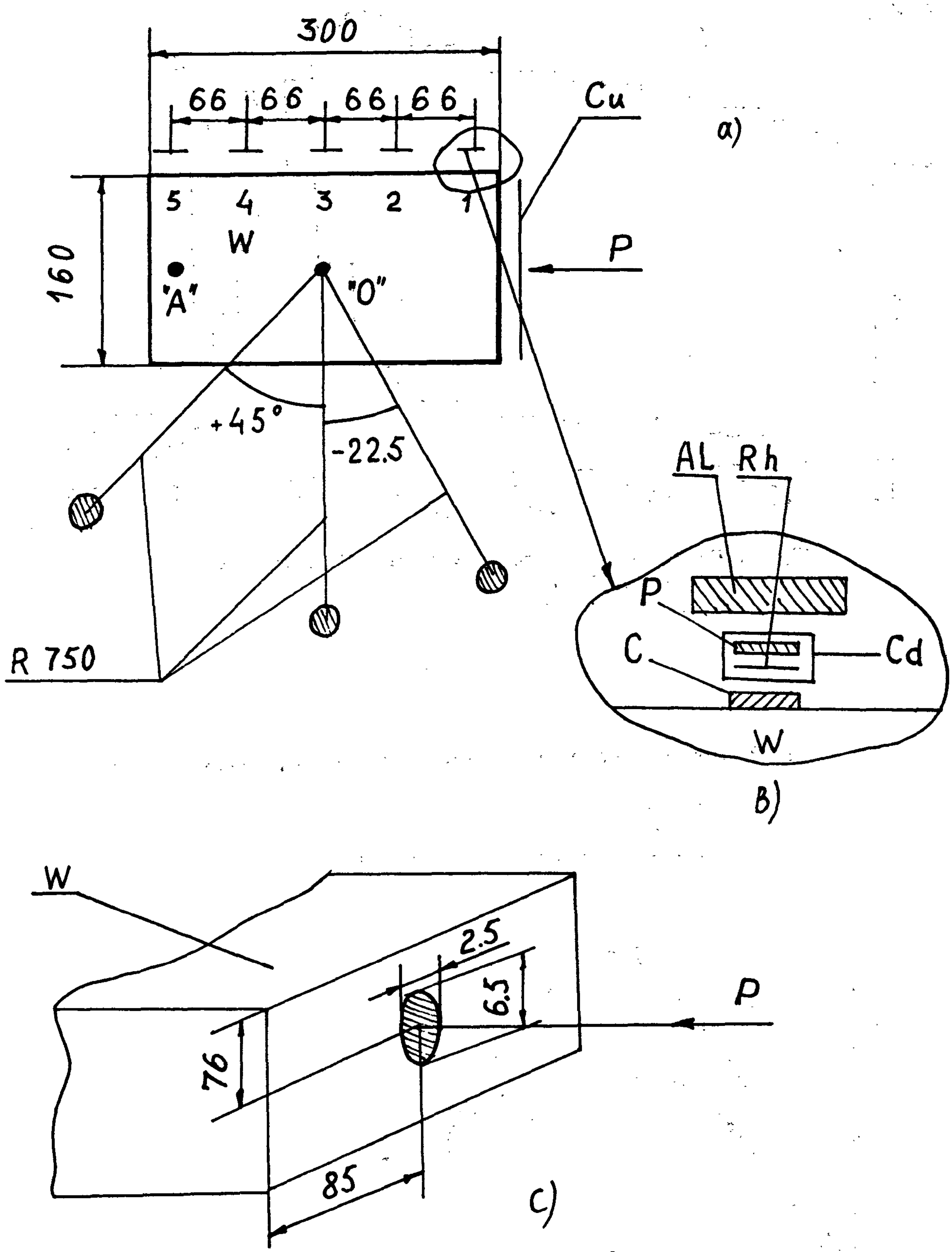


Fig. 1. Scheme of the experiment in 23 canal.
a) position of the detectors around the target
b) set of detectors
c) position of the proton beam

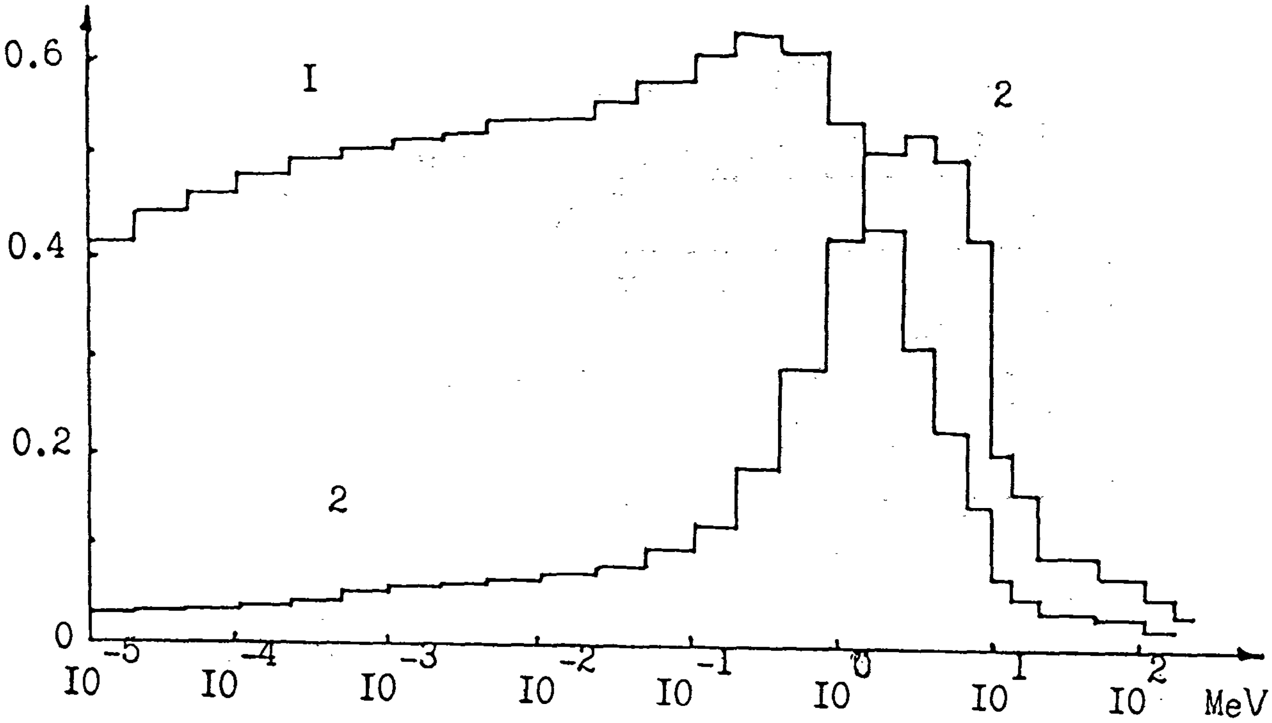
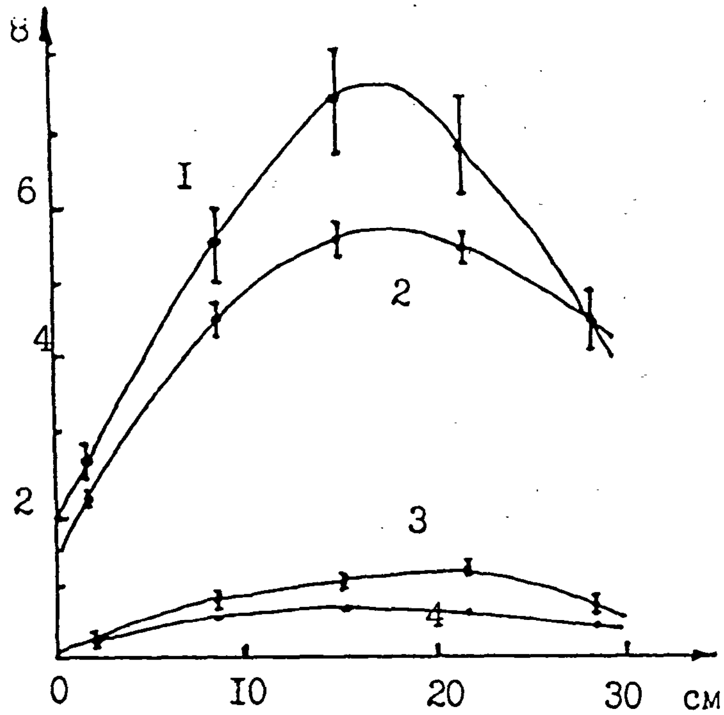


Fig. 2. Function of the sensitivity of ball detectors
1 - d127 mm
2 - d254 mm

Fig. 3. Distribution of the neutron flux on the target surface
1 - P
2 - Al
3 - C
4 - Rh (without self-absorption)



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