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NEUTRON FIELD MEASUREMENTS BY GFPC BASED MONITORS AT THE CARBON BEAM OF IHEP U-70 PROTON SYNCHROTRON

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Abstract

Neutron monitors with gas filled proportional counter (GFPC) as a sensitive element were presented at RuPAC-2018. These monitors have been used recently to measure fast neutron fluxes near the carbon beam based experimental facility at IHEP. The experimental facility "Radiobiological test setup at the U-70 accelerator" was built at NRC "Kurchatov Institute" - IHEP, Protvino, to carry out radiobiological and physical experiments with the extracted beam of carbon nuclei with an energy up to 450 MeV/nucleon. The measurements were compared with the CERN FLUKA code simulations.

INTRODUCTION

Neutron detection by GFPC monitors [1] is based on thermal neutron capture reaction by a 10B nucleus with emission of α particle. Incident neutrons are moderated to thermal energies by a moderator layer surrounding a corona counter SNM-14. The internal surface of the counter is covered with amorphous boron, with the 10B isotope content enriched up to 80-85%. The counter is filled with argon at atmospheric pressure. A signal is formed mainly after ionization of argon by ions of 4He or 7Li ions. The SNM-14 corona counter in these monitors is operated in proportional mode.

A pair of monitors can be more efficient for detecting high-energy neutrons, provided the response curve of the complementary (light) monitor is close to the response curve of the main (heavy) monitor below 100 keV and much lower at high energies. Each of the types of monitors can work independently as a neutron flux counter. Efficiency of the separate monitor will be determined by its response function and neutron spectrum in the monitor location. Pair of monitors works as a simplest spectrometer dividing the neutron spectrum in two groups.

The monitors are intended to work without intervention for a long period of time. They are controlled via a single coaxial cable (for both data and power supply) and are relatively small. The monitors themselves and their front-end electronics are radiation hard, and their operation is not affected by the magnetic field.

The main goal of these measurements was testing of the recently developed neutron monitors in a typical high energy neutron field at the Radiobiological Stand (RBS) facility [2]. The RBS layout is shown in Fig. 1, where big letters C point to the carbon beam axis at the entrance to and at the exit from the RBS area. The height of the beam axis with respect to the concrete floor is 215 cm.

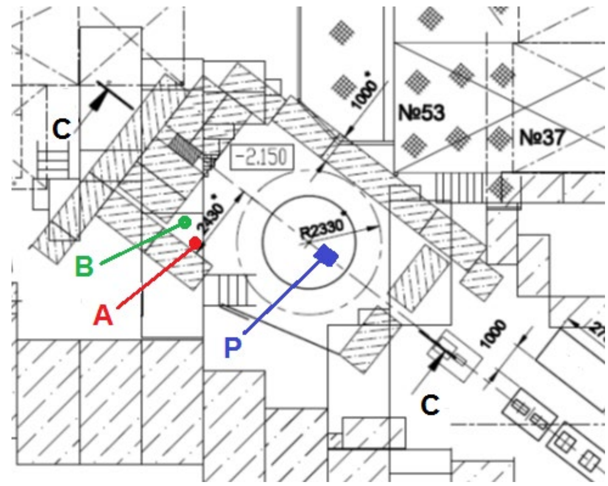

Figure 1: Schematic top view of the RBS facility. A and B – pair of the neutron monitors, C – ion beam, P – water phantom.

The wide beam passes through the collimator opening of 5×5 cm and approximately 50% of the beam hits the water phantom installed on the top of the medical bench. The main source of neutrons is the beam interaction with phantom and interactions with collimator material produce background source.

Passed beam is monitored by a flat air-filled ionization chamber of 20×20 cm area. The beam energy is 434 MeV/nucleon. Irradiation was done with 236 cycles, consisting of 0.6 s long pulses with 8 s spacing between them. The RBS area is surrounded by concrete shielding blocks and the monitors were placed inside shielding but not too close to the beam axis. Monitor coordinates are given in the Table 1.

Table 1: Transverse X, Vertical Y and Longitudinal Z Coordinates of the Monitor Centers With Respect to the Phantom Center

Monitor	X, cm	Y, cm	Z, cm
A	196	-103	332
B	167	-103	361

The main (heavy) monitor (monitor A through this report and in Fig.1) measured the fluence of fast neutrons (with energy greater 100 keV). The complementary (light) monitor (B through this report and in Fig.1) was used for the correction of the monitor A readings.

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MEASUREMENTS

Figure 2 shows the dependence of the measured count rates on the beam intensity (blue and black dots for monitors A and B respectively). The dependence of the measured rates N'A and N'B is linear within 3% at the count rates below 6000 counts/cycle or 10 kHz. At higher rates the effect of the counter "dead time" breaks this linearity.

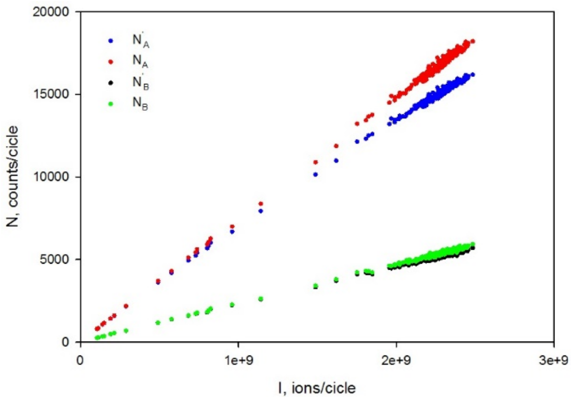

Figure 2: Monitor count rate as a function of the ion beam intensity.

For GFPC the effect of the "dead time" can be expressed as follows:

$$\frac{N'}{T} = \frac{N}{T} \times \exp(-S \times \frac{N}{T}),$$

where T is the pulse duration, S is the "dead time", N'/T is the measured count rate and N/T is the "true" count rate. Then the ratio of the measured counts of the monitors A and B can be derived as:

$$r(N_B) = \frac{N'_A}{N'_B} = \frac{N_A}{N_B} \times \exp\left(-N_B \times \frac{S}{T} \times \left(\frac{N_A}{N_B} - 1\right)\right) =$$
$$R \times \exp\left(-N_B \times \frac{S}{T} \times (R - 1)\right),$$

where r and R are the ratios of the measured and "true" counts respectively. Let's fit the dependence $r(N_B)$ by the function $a \times \exp(-b \times N_B)$, where a = R, b = S / T × (R - 1) and iterate N_B. The iteration results are shown in the Fig. 3 and presented in the Table 2.

Finally, the estimated "dead time" S equal to 3.87 μs was used to convert the measured counts to the "true" ones. These "true" counts of monitors A and B are presented in Fig. 2 by the red and green dots respectively. Their dependence on the beam intensity is quite linear even at high count rates. Green dots are almost coinciding with black ones.

Based on the "true" counts of the monitor A value of the fast neutron fluence at the location of the monitor A is equal to 7.4×10^{-6} n/cm^2 per one beam ion.

SIMULATIONS

Neutron energy spectra were calculated on the base of Monte Carlo simulations of nuclear cascades initiated by the ion beam in the RBS. CERN FLUKA code v.4-1.1 [3] was used for these simulations. Calculated spectra at the location of our monitors A and B are shown in Fig. 4. They were used to obtain the value of the fast neutrons fluence. In combination with the response functions of our monitors from [1] they allow to estimate the monitor count rates.

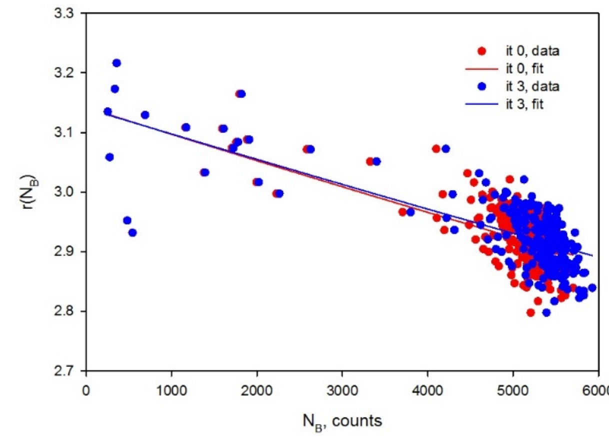

Figure 3: Ratio of the monitor counts as a function of number of "true counts" of the monitor B.

Table 2: The Iteration Results

#	<N_A/I> × 10^6	<N_B/I> × 10^6	<N_A/N_B>	R	S/T × 10^6
0	6.64	2.27	2.921	3.142	6.724
1	7.42	2.36	3.152	3.141	6.455
2	7.39	2.35	3.141	3.141	6.465
3	7.39	2.35	3.141	3.141	6.464

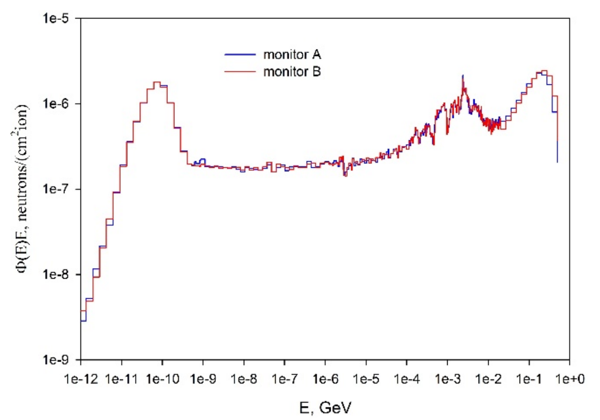

Figure 4: Neutron energy spectrum at the location of monitors A and B.

Results of these calculations are presented in the Table 3 along with the measured values.

The measured value of the fast neutron fluence at the location of the monitor A corresponds to the calculated one within 15%.

CONCLUSION

System of two recently developed GFPC neutron monitors was used for measurements of the neutron field around the Radiobiological Stand facility at IHEP. The monitor A (heavy, or main) was used to measure the fluence of fast

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neutrons, the monitor B (light, or complementary) - to estimate the GFPC "dead time" and thus to correct the readings of monitor A at the count rates exceeding 10 kHz. A good agreement of the measured and simulated with FLUKA code values gives us a preliminary validation of our interpretation of the main monitor as a fluence meter, though the interpretation efforts must be continued for other types of the neutron spectra.

Table 3: Comparison of the Calculated and Measured Values

Type	Fast neutron fluence, n/cm2/ion	Calculated, counts/ion	Measured, counts/ion
A	7.69×10^{-6}	7.91×10^{-6}	7.39×10^{-6}
B	8.43×10^{-6}	2.04×10^{-6}	2.35×10^{-6}

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