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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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The main goal of these measurements was:

rather testing of the recently developed neutron monitors [1] in a typical neutron field of a high energy accelerator,

than a comprehensive study of the neutron field at the Radiobiological Stand (RBS) facility [2].

The measurements were strongly supported by the set of extensive simulations using the well-known FLUKA code [3].

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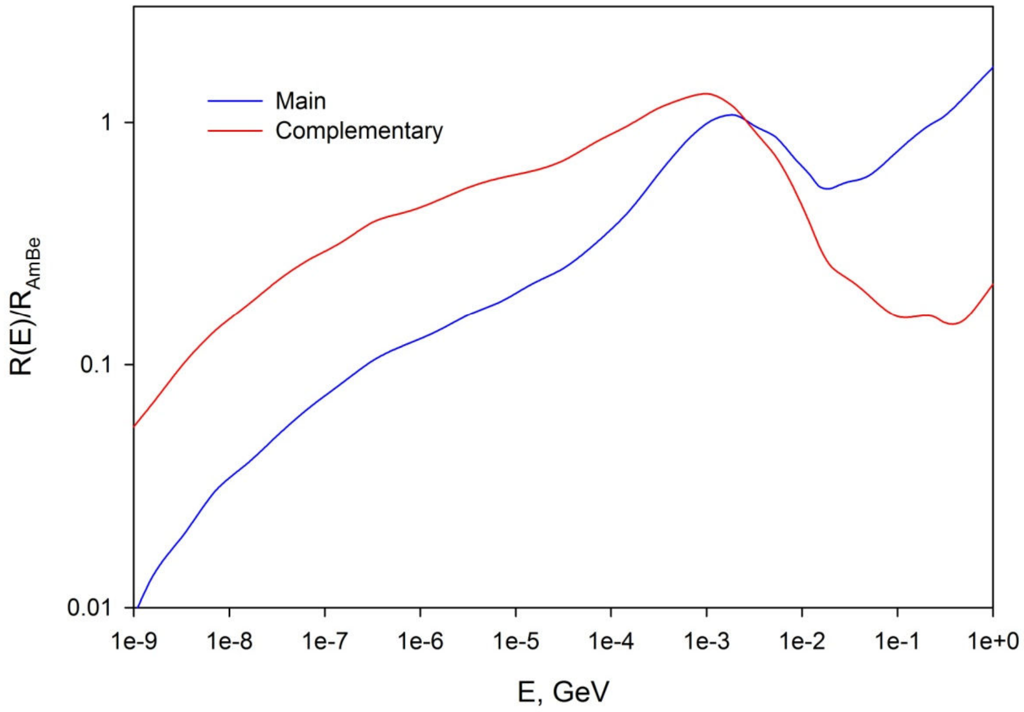
Neutron monitors with gas filled proportional counters (GFPC) inside were presented at RuPAC-2018.

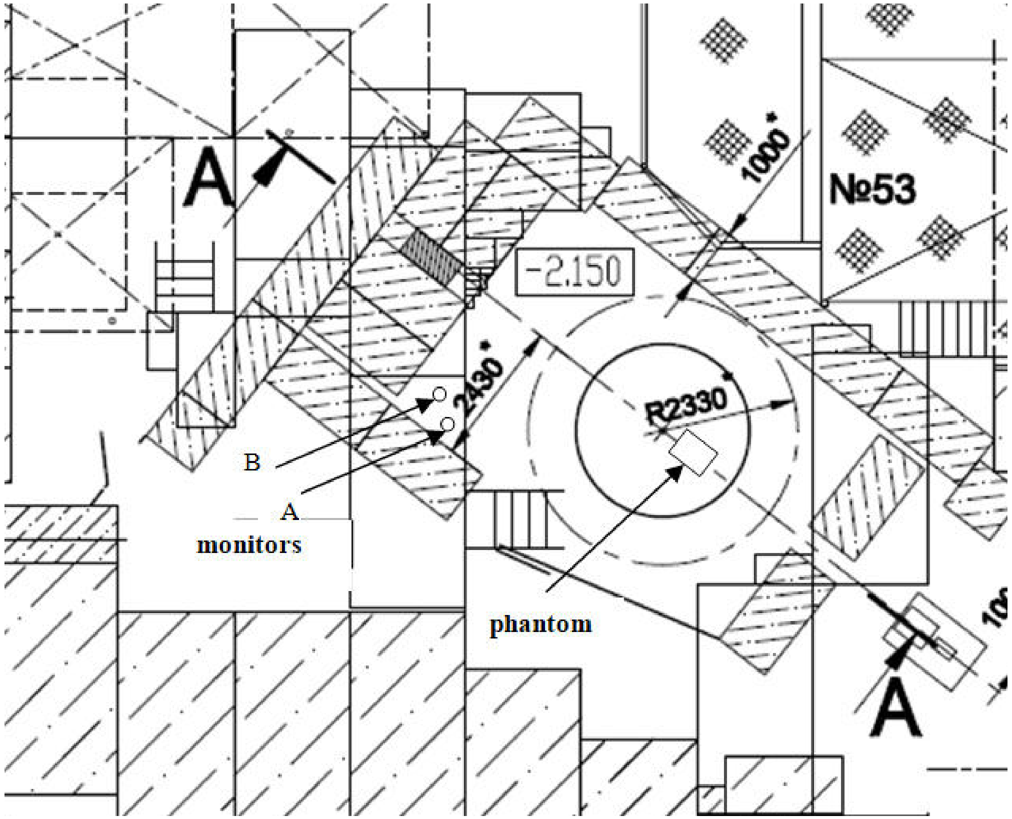


MONITOR A (Main) –
CH2 +PB+CD, $K_{AmBe} = 1.002$

MONITOR B (Complementary) –
CH+CD, $K_{AmBe} = 3.218$

Intended Use:

1. Monitoring of neutron field intensity and spectrum.
2. Fast neutron fluence (E > 100 keV) measurements, using main monitor A (~ 15 % in typical accelerators spectra).
3. Use complementary monitor B for correction in soft spectra.



Schematic top view of the RBS facility

BEAM:

Wide beam of C12 ions with energy 434 MeV/n.

Collimator 1 is opening of 5x5 cm (~ 50 % ions through).

Timing: 236 cycles, consisting of 0.6s long pulses with 8s spacing between them.

Beam intensity was monitored by a flat air filled ionisation chamber of 200×200 mm area.

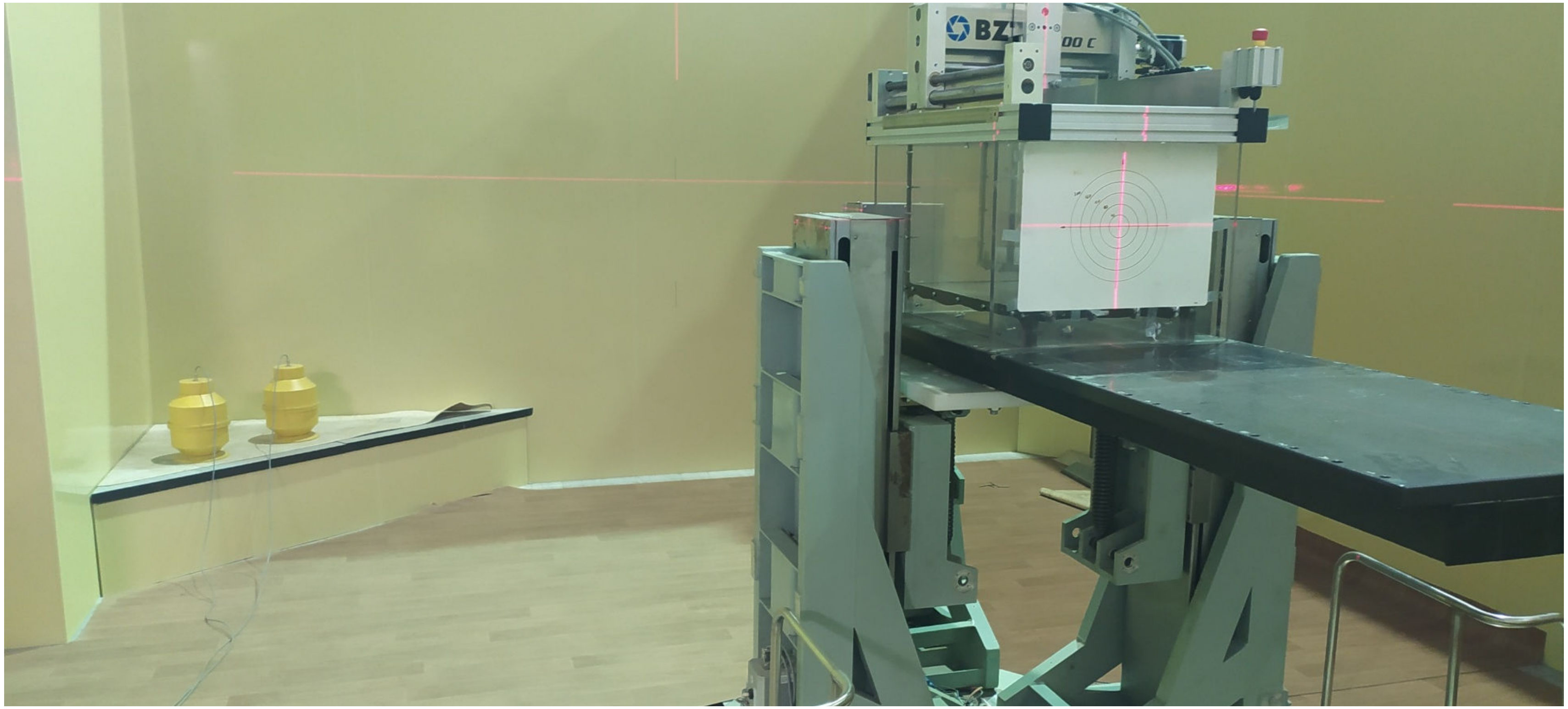
TARGET:

Water filled phantom IHEP, placed on the table at beam axis.

Internal size – 33x35x53 cm

Walls – polycarbonate, bottom and side – 1.5 cm, front and end – 3 cm.

Water level – 30 cm.



View inside the RBS facility before measurements.

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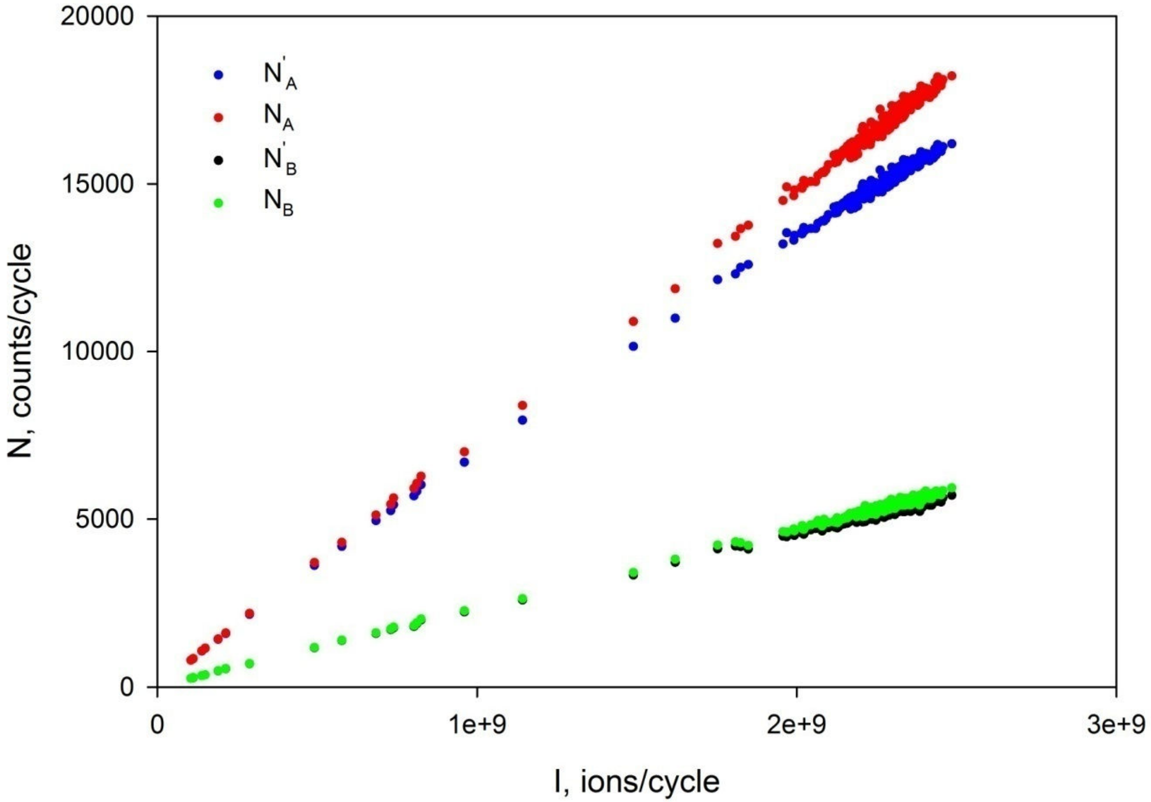
MEASUREMENTS



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.

“Dead time” correction:

$$\frac{N'}{T} = \frac{N}{T} \cdot \exp\left(-\tau \cdot \frac{N}{T}\right),$$

where T is the pulse duration, τ is the “dead time”, N’/T is the measured count rate and N/T is the “true” count rate.

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

where r and R are the ratios of the measured and “true” counts respectively.

Fit the dependence $r(N_B)$ by the function $a \cdot \exp(-b \cdot N_B)$, where a=R, b= τ/T (R-1).

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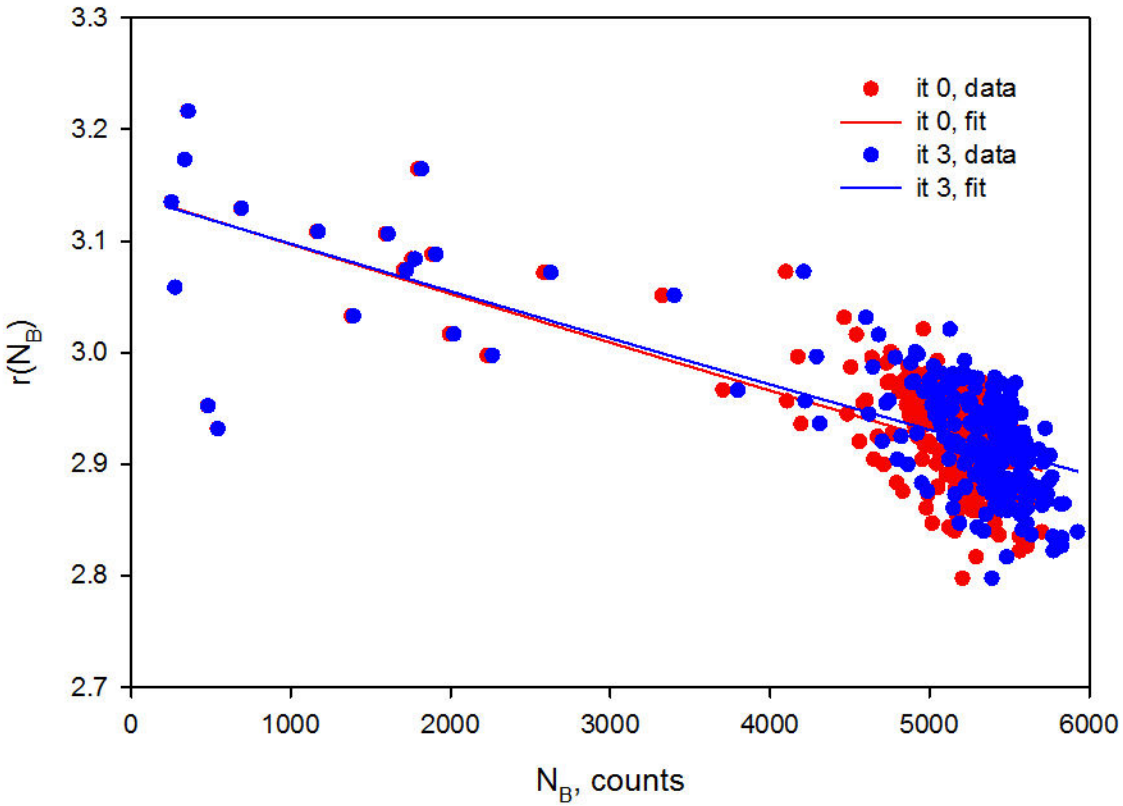
“True” counts – N_B is unknown, so we need iterate N_B.

$$N_{B0} = N'_B$$

$$N'_B = N_{Bi} \cdot \exp\left(-N_{Bi} \cdot \frac{\tau_{i-1}}{T}\right).$$

№	<N_A/I>	<N_B/I>	<N_A/N_B>	R	τ/T
0	6.64 10^{-6}	2.27 10^{-6}	2.921	3.142	6.724 10^{-6}
1	7.42 10^{-6}	2.36 10^{-6}	3.152	3.141	6.455 10^{-6}
2	7.39 10^{-6}	2.35 10^{-6}	3.141	3.141	6.465 10^{-6}
3	7.39 10^{-6}	2.35 10^{-6}	3.141	3.141	6.464 10^{-6}



Ratio of the monitor counts vs “true” counts of the monitor B in iterative procedure.

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The estimated “**dead time**”:

$$\tau = 3.87\ \mu s.$$

“TRUE” COUNTS correction:

$$N' = N \cdot \exp(-N \cdot \tau / T)$$

$$\frac{N}{N'} = 1.006 + 2.571 \cdot 10^{-6}\ \frac{N'}{T} + 6.167 \cdot 10^{-11}\ \left(\frac{N'}{T}\right)^2 \quad (1 - 100\ \text{kHz}, \sim 1\%)$$

Based on the “true” counts Neutron fluence at the location of the monitor A:

7.4×10^{-6} cm^{-2} per beam ion.

SIMULATIONS

Spectra at the location of our monitors A and B were calculated on the base of simulations of ion beam initiated nuclear cascades in the RBB area using the well-known code FLUKA.

They were used to obtain the value of the fast neutrons fluence and to estimate the expected monitor count rates:

$$N_0 = \frac{1}{K_{AmBe}} \int \Phi(E) \cdot R(E)/R_{AmBe} \cdot dE$$

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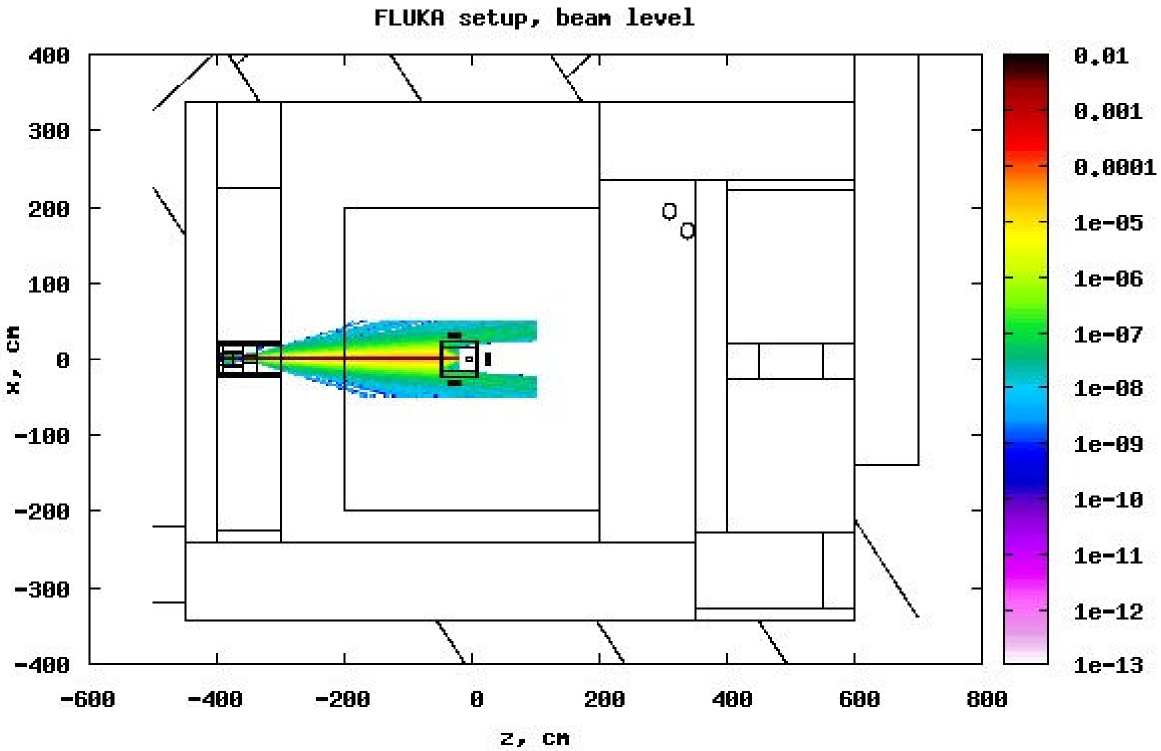
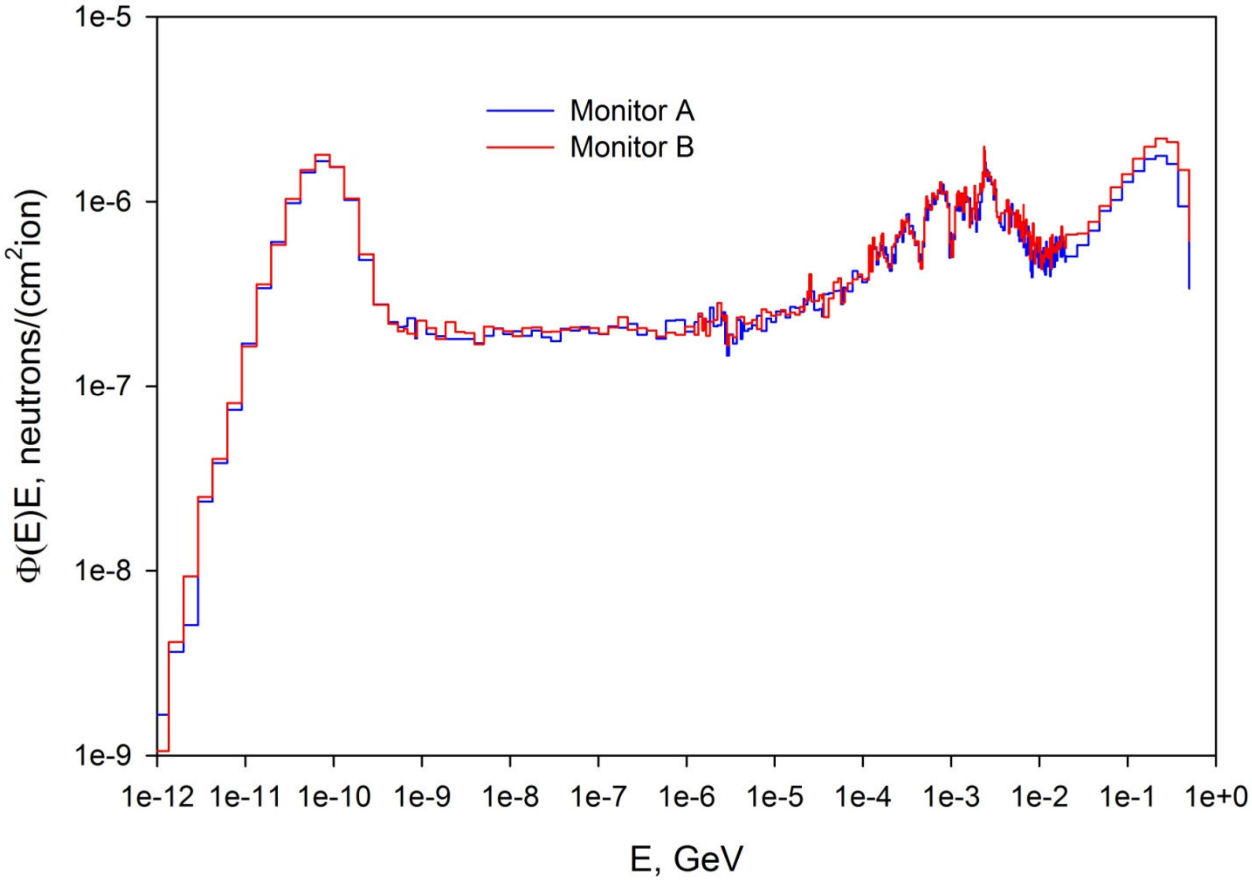


FLUKA simulation setup at beam level with phantom, beam and monitors positions.



Neutron energy spectrum at the location of monitors A and B. FLUKA simulation.

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Comparison of calculated and measured values.

value	Measured	calculated
Fast neutron fluence, cm^{-2}/ion, monitor A location.	7.40×10^{-6}	7.69×10^{-6}
counts/ion, monitor A	7.39×10^{-6}	7.91×10^{-6}
counts/ion, monitor B	2.35×10^{-6}	2.05×10^{-6}
Counts ratio, monitor A / monitor B	3.14	3.87

CONCLUSION

Two recently developed neutron monitors were used for measurements in the area of the Radiobiological Stand facility at IHEP: the monitor A - to measure the fluence of fast neutrons, the monitor B – 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 simulated with FLUKA and measured values gives us a preliminary validation of our interpretation of the main monitor as a fluence meter, though the interpretation efforts must be continued.

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[1] I.L. Azhgirey, I.S. Bayshev, I.A. Kurochkin, V.A. Pikalov, O.V. Sumaneev, V.S. Lukanin, “Neutron Monitors for High Energy Accelerators”, TUPSA38, Proceedings RuPAC2018, Protvino, Russia, pp.224-226.

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[3] G. Battistoni, T. Boehlen, F. Cerutti, P.W. Chin, L.S. Esposito, A. Fassò, A. Ferrari, A. Lechner, A. Empl, A. Mairani, A. Mereghetti, P. Garcia Ortega, J. Ranft, S. Roesler, P.R. Sala, V. Vlachoudis, G. Smirnov, "Overview of the FLUKA code", Annals of Nuclear Energy 82,2015, pp.10-18.