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Neutron-physical parameters at the outlet of the WWR-K reactor beam tube

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The paper is devoted to the neutron-physical parameters obtained via combined calculations and experimental measurements for the exit of the WWR-K reactor beam tube. The experimentally measured values of the thermal and fast neutron flux densities at the exit comprise 9.6×10^{8} and 8.4×10^{7} cm $^{-2}$ s $^{-1}$, respectively. The dose rate of gamma-emission is 30 Sv/h. The obtained parameters will be used in designing of the collimation and screening systems of the installation for radiography and tomography to be created at the beam tube #1.

Keywords: WWR-K reactor, neutron spectrum, neutron beam, MCNP, neutron flux.

Introduction

The WWR-K is a 6-MW research tank-type steady state heterogeneous reactor with thermal neutron spectrum [1]. Desalted water serves as neutron moderator and coolant. Water and beryllium are used as neutron reflector. Reactor appearance is shown on Figure 1. The maximum thermal neutron flux density achieves 2×10^{14} cm $^{-2}$ s $^{-1}$. Reactor is equipped with two-circuit cooling system. Heat transfer from primary circuit to secondary one is implemented via heat exchangers. In primary circuit coolant circulation is forced and direction is downward [2, 3].

The main current areas of the WWR-K reactor application are: in-reactor tests of fuel and structural materials of prospective reactors (including radiation tests of functional materials of thermonuclear reactors), production of radioactive isotopes for medicine and industry, neutron-activation analysis.

The beams (nine radial and a tangent one) and vertical channels are available, in view of fundamental and applied studies. Modern installation of neutron radiography and tomography is expected to be built at the beam tube #1 [4, 5]. This work is carried out jointly with the JINR Frank Laboratory of Neutron Physics.

Figure 1. The WWR-K research reactor.

In order to improve the quality (resolution) of neutron images to be obtained, a decision was taken to install supplementary a neutron guide after the channel gate as continuation of the channel. The neutron guide represents steel tube of a diameter 428 mm and a length of 5 m, vacuum is inside. A requirement to enlarge the neutron guide length is related to the radiography installation characteristic parameter L/D, where L is the aperture length and D is the neutron beam diameter.

After a series of pilot experiments at the radiography facility, a decision was taken on widening its functionality - via varying the neutron beam diameter (collimation system) and cutting off some components of reactor radiation (screening system). Screening system is purposed to absorbing of fast neutrons and photons. The maximum thermalized neutron spectrum should be in the sample installation zone to increase the efficiency of the facility. The proper and effective designing of the collimation and screening systems implies knowledge of relevant neutron physical characteristics of a beam.

This paper presents general results of the combined experimental and calculation studies of neutron-physical parameters of the WWR-K reactor beam tube #1. Location of the beam tube #1 in the WWR-K reactor is shown on Figure 2.

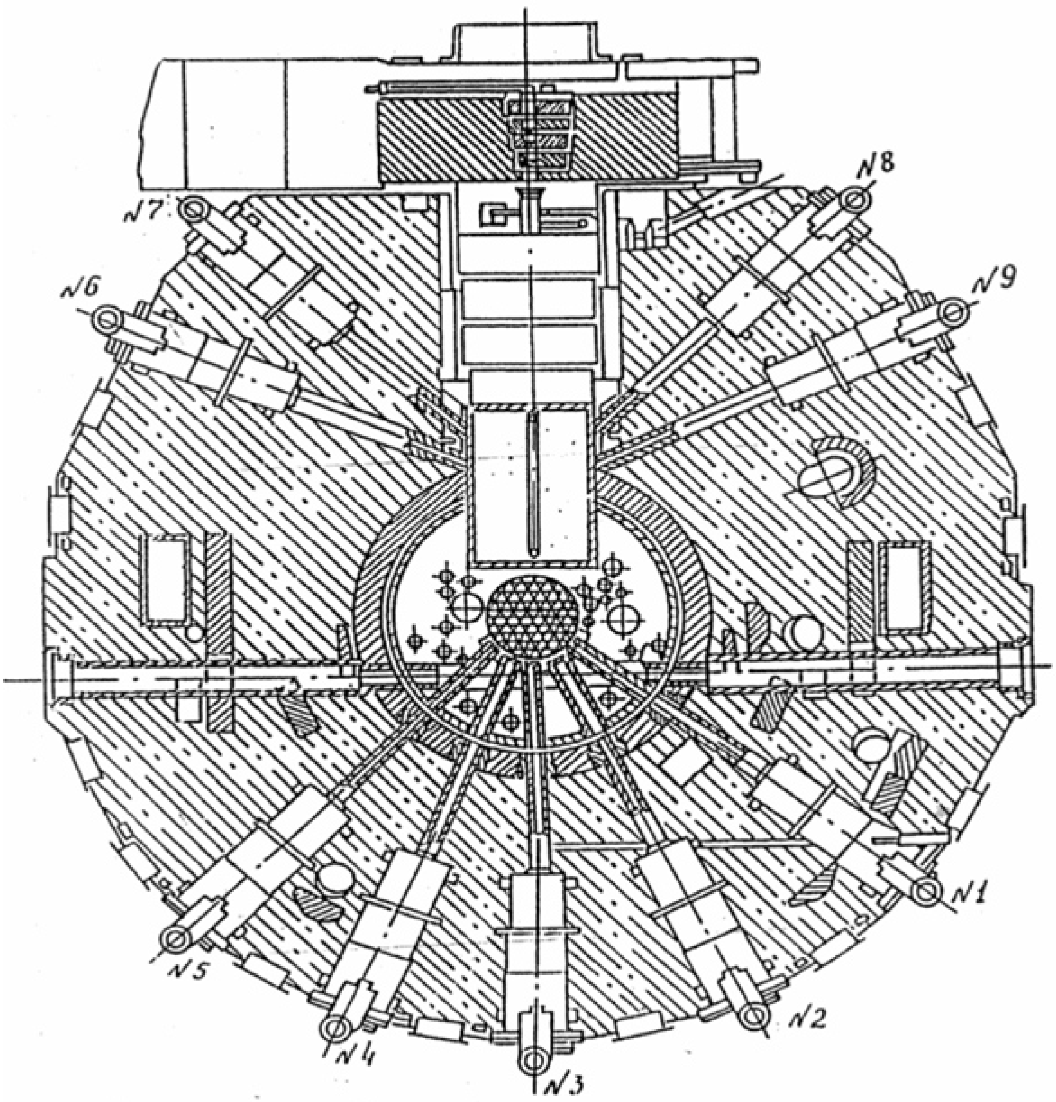

Figure 2. Schematic view of the WWR-K reactor with beam tubes.

Materials and Methods

The activation technique was used in experimental studies of the neutron flux density. Certified detectors were used. The detectors made of gold (^{197}Au) were applied with and without cadmium screen (to separate thermal component), whereas indium (^{115}In) detectors were used as threshold ones. Measurements were carried out at the beam tube (just after the channel gate) and at the exit of the neutron guide. It should be marked that all detectors were in air environment.

The experimental measurement of the dose rate of gamma emission was carried out by means of the Canberra STHF-R portable unit for detection of gamma emission. Silicon diode is used as a detector in the unit. The maximum measured gamma emission dose rate is 1000 Sv/h.

Prior to a start of experimental studies, expected values should be known - the neutron-physical characteristics of the beam tube in our case. Then one can choose a proper experimental technique and may estimate an impact of the experiments on safety. That is why experimental work is accompanied by preliminary calculations.

The neutron-physical parameters were calculated with the computer code MCNP [6, 7]. MCNP is a computer code based on Monte Carlo technique. Monte Carlo can be used to duplicate theoretically a statistical process (in our case the interaction of nuclear particles with materials) and is particularly useful for complex problems that cannot be modeled by computer codes that use deterministic methods. The individual probabilistic events that comprise a process are simulated sequentially. The statistical sampling process is based on the selection of random numbers - analogous to throwing dice in a gambling casino - hence the name "Monte Carlo". In particle transport, the Monte Carlo technique is pre-eminently realistic (a numerical experiment). Detailed three-dimensional calculated model of the physical objects with specified material composition can be built in the code environment by mathematical means. An accuracy of calculations depends on the accuracy of a user-specified model (geometry and material composition) and on a number of simulated histories of neutron-substance interactions. The Monte Carlo technique relative error is proportional to $1/\sqrt{N}$, when N is a number of neutron histories. Relative error is the defined to be one estimated standard deviation of the mean divided by the estimated mean.

Here we use heterogeneous model of reactor, that is, every component of the reactor and the core is described separately: the core with fuel assemblies, CPS control, rods, beryllium blocks of side reflector andirradiation channels, reactor tank, biological shield and beam. Screenshot of the calculated model is shown on Figure 3.

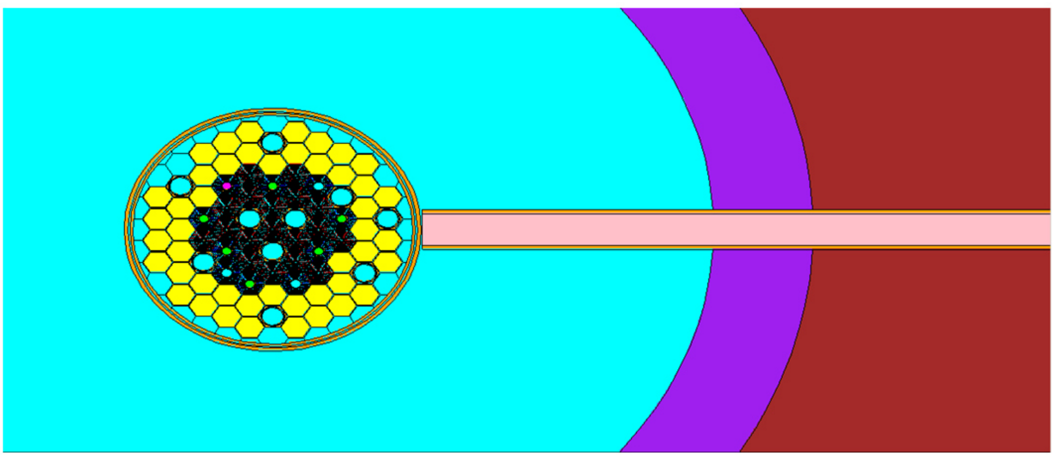

Figure 3. Schematic view of the computer model.

Table 1.
The neutron flux density at outlet of the beam tube #1.

Detector location	Thermal neutron flux density cm^{-2} s^{-1} (E_n<0.625 eV)			Fast neutron flux density cm^{-2} s^{-1} (E_n>1.15 MeV)		
	calculation (C)	experiment (E)	E/C	calculation (C)	experiment (E)	E/C
beyond gate	$(8.3\pm0.5)\cdot10^8$	$(9.63\pm0.67)\cdot10^8$	1.16	$(1.9\pm0.1)\cdot10^8$	$(0.842\pm0.007)\cdot10^8$	0.44
beyond neutron guide	-	$(1.09\pm0.07)\cdot10^8$	-	-	$(1.28\pm0.01)\cdot10^7$	-
beyond filter-collimatorwith sapphire	-	$(1.42\pm0.10)\cdot10^7$	-	-	$(7.04\pm0.56)\cdot10^5$	-

Table 2.
The gamma-dose rate at the outlet of the beam tube #1.

Detector location	Dose rate, Sv/h
beyond gate	30.15±0.06
beyond filter-collimator	0.5616±0.0001

Results and Its Discussion

As a result of the performed calculation-experimental studies, the neutron-physical characteristics of the WWR-K beam tube #1 are obtained (see Table 1 and Table 2).

The data given in Table 1 and Table 2 are obtained with sapphire filter and borated polyethylene collimator. The thermal neutron flux density at the outlet of the neutron guide decreased by 9 times (see Table 1). The neutron loss was reduced due to the created vacuum environment inside the neutron guide.

The experimentally measured distribution of the neutron flux density over the neutron guide diameter is shown on Figure 4.

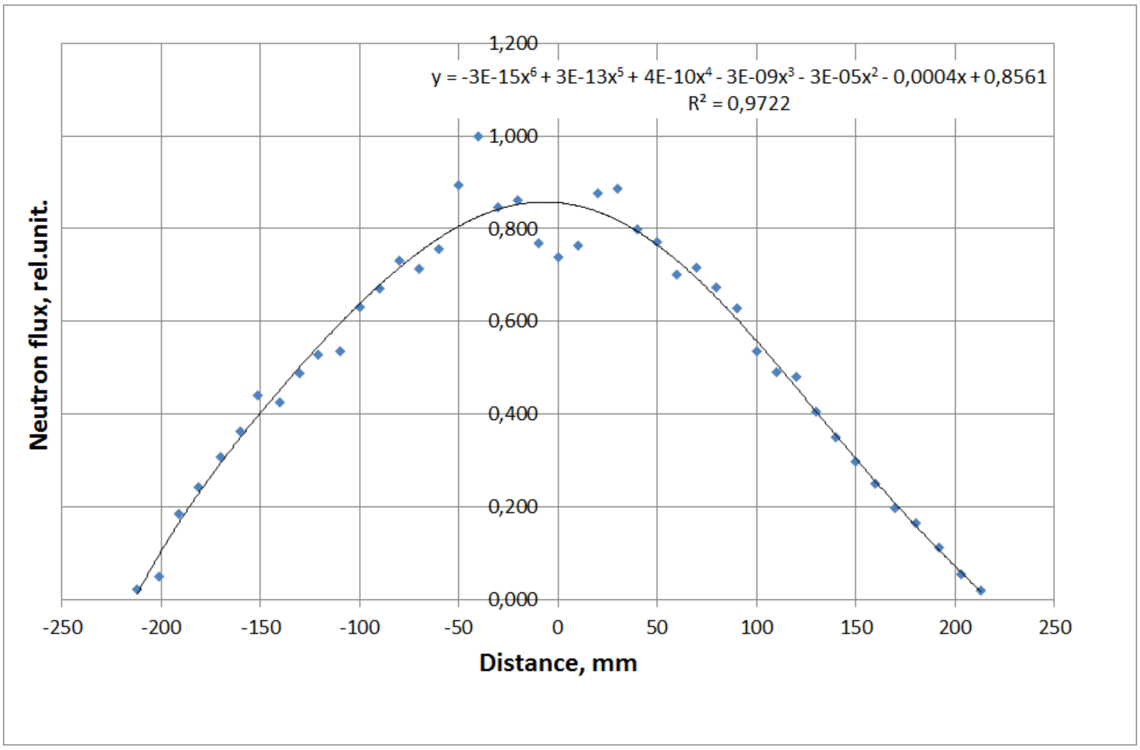

Figure 4. Spatial distribution of neutrons over diameter of the neutron guide (vertical plane).

The obtained results of the experimental studies show that sapphire is an effective filter of fast neutrons. The thermal neutron flux beyond sapphire screen was decreased to 8 times and the fast neutron flux was decreased to 18 times. The system of screening with an option of filter changing will widen functionality of the radiography installation to be created.

Conclusions

The neutron-physical characteristics of the WWR-K reactor beam tube #1 have been studied. The obtained data will be used when designing the systems of collimation and screening for the installation of radiography and tomography.

At the outlet of the beam tube #1, the thermal and fast neutron flux density is, correspondingly, (9.6×10^{8}) and (8.4×10^{7}) $cm^{-2}s^{-1}$, the gamma emission dose rate comprises 30 Sv/h.

In view of neutron thermalization and cutting fast neutrons offin the installation of specimen location area, the sapphire was considered as potential candidates for a role of screen.

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