Development of various configuration of moderators for measuring Neutron fluxes from the WWR K reactor

Abdulhamid Hasanzada[1], Mohammad Tahir Sharifi [۲]and PhD. Mukhamejanov Y .S[3]

[1,2] Physics Departement, Education Faculty, Nimruz Inistitute of Higher Education.
[3]Institute of Nuclear Physics, 1 Ibragimova str., 050032, Almaty – Kazakhstan.
Email: hasanzadahamid@gmail.com

Abstract

The study of different types of moderators, such as polyethylene and graphite, in the WWR-K (Water-Water Reactor of Kazakhstan) research reactor will always be associated with the study of the properties of the necessary building materials for nuclear energy reactors. Thermal neutron flows in WWR-K reactor. In this Article we applied substances for moderation the fast neutron to slowdown. Determination of thermal neutron flows from the WWR-K reactor with a polyethylene boron-countaining polyethylene moderator and without moderator. A comparison of the results from the computer modeling of The Geant4 and the experiment conducted at the 2022 in WWR-K research reactor. Computer modeling of the process next to the SNM-15 detector in The Geant4 .The reasults in chart shows that detectors with moderators to compar without moderator is different. Without moderators (polyethylene and Boron-polyethylene) detector shows bigger number of neutrons.

Key words*:* Computer modeling, Detector, Geant4, Neutron moderator, Proportional calculator SNM-15, Thermal neutrons.

INTRODUCTION

WWR-K is a heterogeneous tank-type state reactor of the type of 6 MW research reactor with thermal neutron spectrum. Desalinated water acts as a neutron coolant and moderator. Water and beryllium are used as neutron reflectors. Maximum thermal neutron flux density to $2 \times 10^{14} \frac{1}{cm^2 s}$ Reactor is furnished with two-circuit cooling system. Heat transfer from primary to secondary circuit one is implemented via heat exchangers. In first circuit coolant circulation is forced and direction is downward.

The main application 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. In this Article we used polyethylene and, Boron-polyethylene and without any moderators for measuring neutron fluxes and effect of moderators to slow down the neutrons. (Bauyrzhan, Koltochnik, Aitkulov & colleagues, 2019: 220). In history of this research in Nuclear Science and Techniques · September 2016, at article “Optimization of moderator assembly for neutron flux measurement. Experimental and theoretical approaches”8 authors, Nawab Ali, Muzahir Ali Baloch and others also in ELSEVIER publication David V. Baxtera, J. Leungaand others in article “Neutron Moderator Development Research at the Low Energy Neutron Source”, searched about this issue.

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. This work is performed jointly with the JINR Frank Laboratory of Neutron Physics (Takigawa, 2017: 32).

Materials and Methods

The activation technique was used in experimental studies of the neutron flux density. A material such as ordinary water, heavy water, or graphite used in a reactor to slow down high-velocity neutrons, thereby increasing the probability of fission. The moderator of a nuclear reactor is a substance that slows down the speed of neutrons. In traditional nuclear reactors, the moderator is the coolant water. When fast neutrons hit hydrogen atoms in H_2O, their speed is greatly reduced. In this research, in order to reduce the speed of neutrons, we used moderators such as polyethylene and boron in front of the receiver, and we also calculated and compared the neutron flux without moderators (Bulletin of the Russian Academy of Science, 1986).

In reaction Equations: We can write a general nuclear reaction like below.

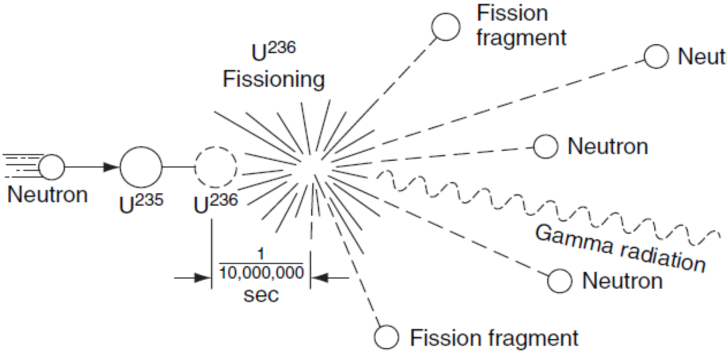
$$A + B \rightarrow C + D\ (1)$$

a simple example of a nuclear reaction is

$${}^{۴}_{۲}He + {}^{6}_{3}Li \rightarrow {}^{9}_{4}Be + {}^{1}_{1}H\ (2)$$

To know how the neutron is created, we consider the following nuclear fission interaction. In fission reaction for uranium-235 as shown in 1 – Figure. In this reaction nea rly 200 MeV of energy, three or two neutrons, two lighter nuclei (known as fission fragments), and several gamma rays and neutrinos are produced by the reaction. Additional fission products are created by the radioactive decay of the fission components. The physics of nuclear power reactors depend heavily on fission energy output, neutrons, and fission products. We think about each one in turn (Elmer, 2008).

Figure –1 a fission reaction



1/2 EXPRIMENTAL DATA

An important feature of the deceleration process is that the loss of energy per collision is proportional to the energy itself. Thus, when colliding with a hydrogen atom, a neutron with an energy of 1 MeV loses 0.5 MeV, and a neutron with an energy of 10eV loses only 5eV. Therefore, the duration of deceleration and the path passable during deceleration are usually weakly dependent on the initial energy of the neutron. Some exceptions are hydrogen-containing substances. The neutron-proton cross-section drops sharply with an increase in energy per 100 keV. Therefore, the length of deceleration in hydrogen-containing substances is relatively dependent on energy. The neutron deceleration time is short. Even in such a heavy moderator as lead, the neutron slows down from an energy of 1 MeV to 1eV in $4 \times 10^{-4}\ s$. (Carron, 2006) .

Starting from energies of 0.5 – 1eV, when neutrons collide with nuclei, the thermal energy of atoms becomes significant. The distribution of neutrons begins to tend to equilibrium, that is, Maxwellian. This process is called neutron thermalization. Neutrons slowed down to thermal energies begin to diffuse, spreading through matter in all directions from the source. This process is already approximately described by the usual diffusion equation with the obligatory consideration of absorption, which for thermal neutrons is always large (in practice, they are made thermal, so that the desired reaction is intense). The main characteristic of the medium describing the diffusion process is the diffusion length L (Nakipov, 1963).

An interesting property of neutrons is their ability to reflect from various substances. This reflection is not coherent, but diffuse. Its mechanism is as follows. The neutron, getting into the environment, experiences random collisions with the nuclei and after a series of collisions can fly back. The probability of such an escape is called the neutron albedo for a given medium. Obviously, the albedo is higher, the greater the scattering cross-section and the smaller the neutron absorption cross-section by the nuclei of the medium. Good reflectors reflect up to 90% of the neutrons that enter them, i.e. they have an albedo of up to 0.9. In particular, for ordinary water, the albedo is 0.8 (Elmer, 2008).

The purpose of the developed technique is to determine the neutron flux density from the WWR-K reactor, based on taking into account the attenuation of the neutron flux by various materials and to create an automatic system that includes a set of equipment for continuous automatic, remote and rapid quantification of the neutron flux from a nuclear reactor in real time (A.B. Bauyrzhan, 2019). The developed equipment is used for the practical use of the method for determining the neutron flux density, which will make it possible to take into account the patterns of spatial change in the neutron field. These neutrons have energies on the order of several MeV and their angular distribution is almost isotropic. Neutrons with an energy of the order of 1 MeV due to elastic and inelastic scattering on the nuclei of the atoms of matter slow down to thermal energies. Thermal neutrons are eliminated from the stream due to radiation absorption to form a gamma quantum, proton or other particles. (Sitenko, 1983: 308). Usually, the dose rate created by neutrons behind the protection is determined, or the found flux densities (fast and thermal) of neutrons are compared with the permissible ones. One of the significant advantages of the proposed methodology is the ability to conduct measurements in real time, unlike most existing methods today. (David, et al., 2012).

To register neutrons, it is planned to create an economical and ergonomic installation. The installation, unlike, for example, LAND and KamLAND, consists of a gas-filled proportional meter SNM-15 and materials for creating various media, such as polyethylene, boron, graphite, beryllium, lead. Counters of this type are successfully used to register neutrons. The registration of thermal neutrons will be carried out by the nuclear reaction ^{10}B (n, α) ^{7}Li in the BF_3 gas enriched with the ^{10}B isotope, which is filled with the meters. The length of the counter is 2m, the diameter is 15cm. Adjustment and preparation of the registration system, development of the electronic part of large-area detectors. When developing equipment for automatic measurement of neutron fluxes from the radiation of the WWR-K reactor, the determining optimization criteria are power consumption, weight, dimensions of the neutron detector. Based on the experimental studies carried out, the optimal levels of supply voltages were determined, and the design of the equipment for automatic measurement of neutron fluxes from the reactor was determined. The main elements of the neutron detector design are as follows:

-Hydrogen-containing moderator unit;
-Neutron detector mounting elements (SNM-18 or similar);
-Design of the amplifier node and microcontroller for analyzing the signal from the detector;
-Node design for high-voltage power supply and signal transmitter.

The amplifier used has been debugged. The amplifier uses original circuit solutions to reduce power consumption. Its frequency response has been optimized to obtain the maximum signal-to-noise ratio 2

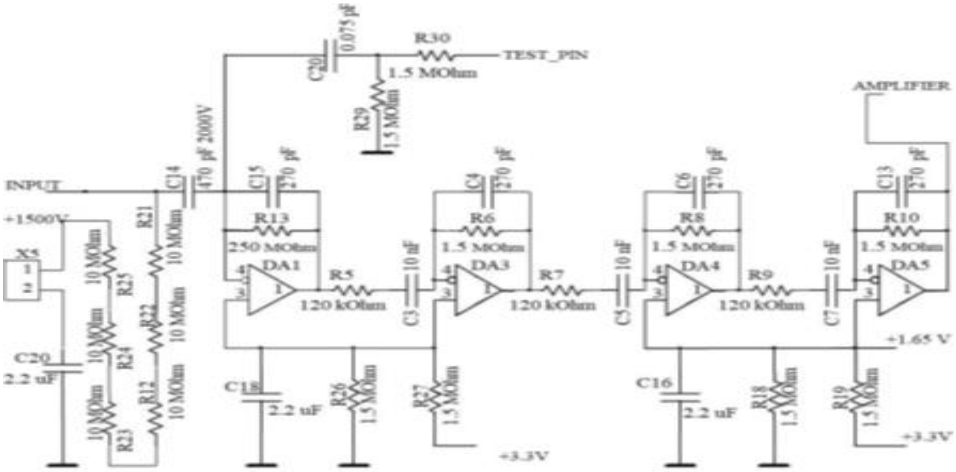
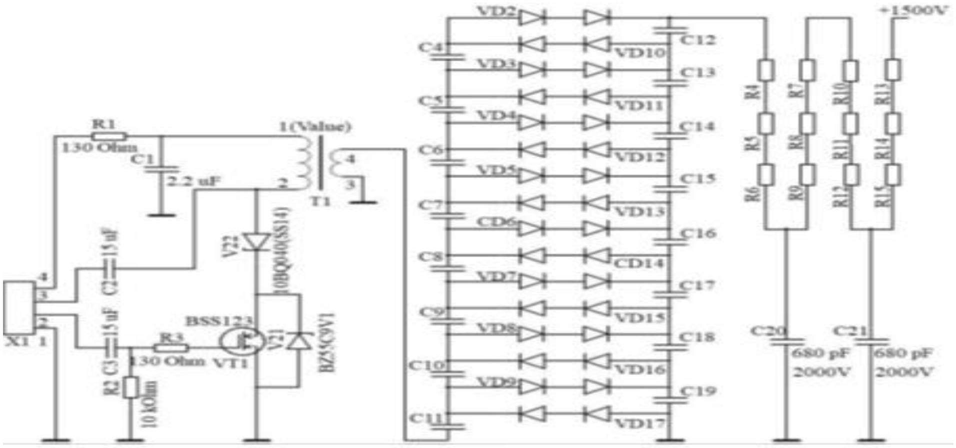


Figure – 2 Schematic diagram of the neutron detector amplifier

Developed high-voltage power board for neutron meters and its circuit diagram is presented in 2 – Figure. To reduce the overall power consumption of electronics, the high voltage was reduced. This led to a decrease in the signal from the neutron counter, which required an increase in the amplification of the electronics. With high gain, the thermal noise of the electronics becomes significant - the signal-to-noise ratio decreases. To improve it, it is necessary to reduce the bandwidth of the amplifier. This can be tuned because the spectral density of the noise is approximately constant, and the spectral density of the signal increases in the low-frequency region, and because in this implementation the signal can be described by the delta pulse integral. Since the estimated neutron



counting rate was below 1 per second, the frequency band was chosen in the 100 Hz region. (Svetlana, et al., 1986).

Figure – 3 High Voltage Circuit Diagram for a neutron detector

The main connection nodes and signal transmission from the equipment for automatic measurement of neutron fluxes from the VVR-K reactor were mounted and installed on the seats. In particular, high-voltage power boards and information removal boards for equipment were installed. For fast signal transmission, a USB 2.0 connector was used 4 – Figure.

Figure – 4 the main connection nodes and signal transmission from the developed equipment for automatic measurement of neutron fluxes.

For registration purposes, it is desirable that the recoil nuclei acquire as large a kinetic energy value as possible. Obviously, the highest values of the kinetic energy of the recoil nuclei will take place at A = 1, i.e. during scattering on hydrogen nuclei. To register neutrons with low energies, a capture reaction by the nucleus of a light element is used, followed by the departure of charged particles. The probability of capturing slow neutrons by lithium and boron nuclei is especially high. When slow neutrons are captured, the target nucleus, such as B^{10}, turns into B^{11}. (Sitenko, 1983: 352).

$$Li_3^6 + n^1 \to Li_3^{7*} \to He_2^4 + H_1^3$$

$$B_5^{10} + n^1 \to B_5^{11*} \to He_2^4 + Li_3^7 \qquad (۳)$$

Since the mass of the nucleus B^{11} is less than the sum of the masses of the nucleus B^{10} and the neutron by 2.78 MeV (neutron binding energy in the boron nucleus), the isotope B11 formed during neutron capture is in an excited state and when it passes into the ground state, a gamma quantum (0.48 MeV) is emitted. Residual energy (2.3 MeV) is released as kinetic energy of reaction products. Since the neutron registration rate is small, the total momentum of the nucleus-neutron system tends to zero, the reaction products fly in opposite directions, and the energy is divided between them inverse proportion to the mass. Consequently, α particle acquires an energy equal to approximately 1.5 MeV, the lithium nucleus - 0.8 MeV. The detectors use as a working substance three-fluoride boron - BF_3 so-called boron counters.

For neutrons with intermediate energies, the method of registration by recoil nuclei is unsuitable, since the ionization effect is quite small. In addition, there are no convenient nuclear reactions in this field of energy, which would be accompanied by the flight of fast charged particles. Therefore, to record such neutrons using a boron neutron counter, it is convenient to first slow down the neutrons to thermal energy using a moderator (the so-called neutron thermalization). When tested in the data collection system for neutron counters, light elements (hydrogen, beryllium, graphite) were used as a moderator, in which the probability of elastic neutron scattering for this energy region is greater than the probability of absorption. For do this, the detector was placed in a large block of paraffin. Neutron, getting into the moderator, experiences in it a number of elastic collisions with the nuclei of the medium. When scattered on free protons, a neutron in each impact loses an average of half of its energy, for example, after 10-15 elastic collisions with a proton, a neutron with energy of 10^2 -10^5eV will be in thermal equilibrium with the environment. When calculating the dimensions of the moderator, the deceleration length was based on the average distance in a straight line from the place where the neutron hits the moderator to the place where the neutron becomes thermal. The length of the deceleration depends on the kinetic energy of the neutron and in water is several centimeters (in graphite 3 times more) .

To record neutrons, thermal neutron detectors surrounded by hydrogen-containing substances (for example, polyethylene, paraffin, boron-containing polyethylene) with a thickness of 25mm and a radio-electronic path unit including a pre-amplifier, a main amplifier, an amplitude discriminator-shaper and an automatic output recorder with a built-in timer and adjustable exposure time were used. The configuration with a graphite moderator has been worked out in the work 5 – Figure. Thermal neutron detectors surrounded by a graphite moderator were used to detect neutrons. Next year, it is planned to work out configurations with such moderators as: polyethylene, borystic polyethylene and beryllium reflector.

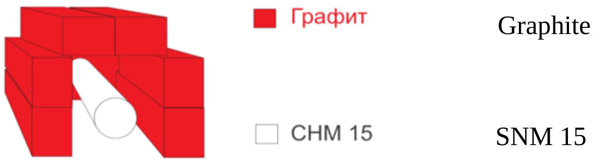


Figure – 5 Neutron spectrum from a neutron counter in graphite

Table –1 Data from registration of neutron from WWR K reactor core with different moderator:

Time,min	Date	Counter in polyethlene	Counter without moderator	Counter in boron-containing polyethylene
1	2022.09.20	0.6333	0.3000	0.1000
2	2022.09.20	0.6833	0.3167	0.0167
3	2022.09.20	0.6333	0.3667	0.0500
4	2022.09.20	0.7167	0.3333	0.0167
5	2022.09.20	0.7500	0.2000	0.0167
6	2022.09.20	0.5500	0.3333	0.0500
7	2022.09.20	0.6667	0.2667	0.0167
8	2022.09.20	0.7500	0.5000	0.0167
9	2022.09.20	0.8000	0.4333	0.0000
10	2022.09.20	0.6167	0.3729	0.0667
11	2022.09.20	0.6500	0.2833	0.0333
12	2022.09.20	0.7167	0.3500	0.0333
13	2022.09.20	0.5833	0.1833	0.0667
14	2022.09.20	0.6333	0.2833	0.0167
15	2022.09.20	0.6833	0.3333	0.0333
16	2022.09.20	0.7167	0.3833	0.0167
17	2022.09.20	0.9000	1.0000	0.1667
18	2022.09.20	3.0000	0.8833	0.2500
19	2022.09.20	3.2333	1.4000	0.1000
20	2022.09.20	3.9500	1.1500	0.2000
21	2022.09.20	3.9667	1.4667	0.2167
22	2022.09.20	3.3333	1.3667	0.1167
23	2022.09.20	3.3833	0.8983	0.1667
24	2022.09.20	2.7333	0.4167	0.0667
25	2022.09.20	0.7667	0.5000	0.0500
26	2022.09.20	0.8333	0.2000	0.0333
27	2022.09.20	0.8333	0.3333	0.0000
28	2022.09.20	0.5333	0.3500	0.0500
29	2022.09.20	0.6833	0.2131	0.0833
30	2022.09.20	0.7167	0.4167	0.0500
31	2022.09.20	0.8500	0.2833	0.0833
32	2022.09.20	0.9333	0.4333	0.0667

33	2022.09.20	0.7667	0.3833	0.1000
34	2022.09.20	0.8833	0.2500	0.0333
35	2022.09.20	0.6500	0.3500	0.0167
36	2022.09.20	0.6500	0.3667	0.0500
37	2022.09.20	0.6333	0.4000	0.0333
38	2022.09.20	0.7333	0.7167	0.0833
39	2022.09.20	1.6167	1.3667	0.1311
40	2022.09.20	3.5000	1.3500	0.2833

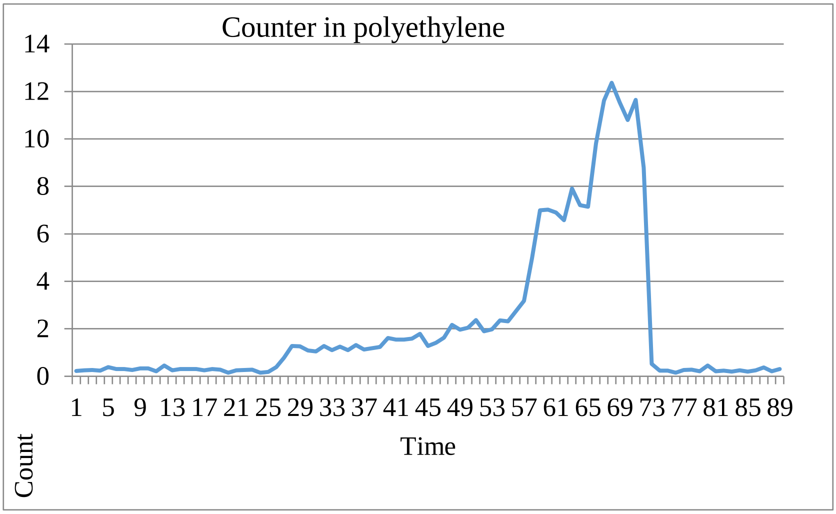


Figure – 6 Counter in polyethylene

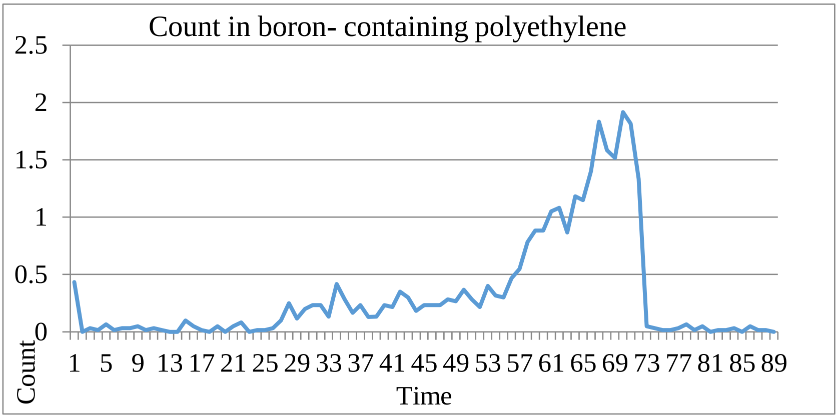


Figure – 7 Counter in boron - containing polyethylene.

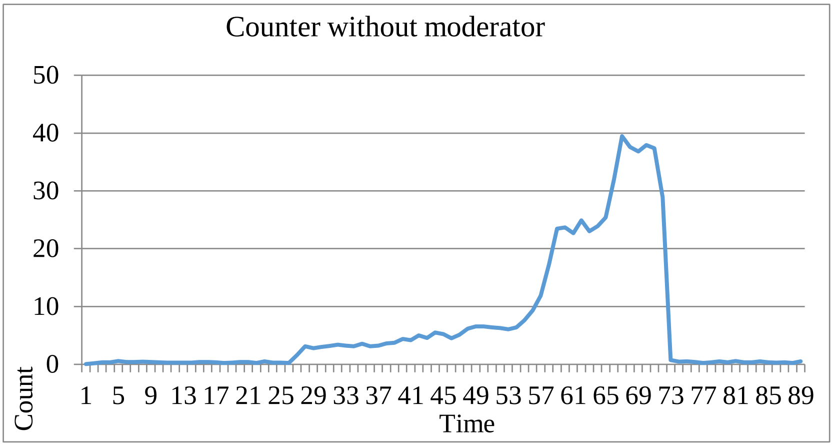


Figure – 8 Counter without moderator

The main purpose of the experiment was to study the interaction of neutrons with the substance and the peculiarities of scattering and absorption in different environments. The equipment chnm-15 for neutron events is composed of a proportional gas meter and materials for the creation of various environments such as polyethylene, boron, graphite, beryllium, lead. The countdown is filled with 10B isotope-enriched BF_3 gas. The registration of thermal neutrons was carried out on the basis of a nuclear reaction of ^{10}B (n, α) ^{7}Li .The results of the experiment gave a quantitative assessment of the intensity of neutron flow. (Jeffrey, King, Mencarini, Lamartine & other, 2015: 4-5).

Research Findings

Slowing down is the process of reducing the initial high kinetic energy of free neutrons. Because energy is conserved, this reduction of neutron kinetic energy is done by transferring energy to a substance known as a moderator. This substance is also known as a neutron decelerator, because it decreases the speed at the same time as the energy decreases. Good moderators have free neutron absorbing impurities such as boron. In commercial nuclear power plants, the moderators usually contain dissolved boron. The boron concentration of the reactor coolant can be manually controlled by operators by adding boric acid or diluting it with water. We checked the performance of moderators boron-polyethylene, polyethylene and also the lack of moderators in reducing the speed of neutrons. Before this research, articles about moderators and its types such as "Neutron Moderator Development Research at the Low Energy Neutron Source" and "Cold Moderators for Pulsed Neutron Sources" has been published by some researchers such as David V. Baxter and others and John M. Carpenter, but I doubt that an article with this exact title has not been published yet.

Conclusion

A technique has been developed and is being worked out to determine the neutron flux density from the WWR-K reactor, based on taking into account the attenuation of the neutron flux by various materials such as polyethylene and boron- containing polyethylene in the laboratory. In this article and research, moderator materials such as polyethylene and boron-polyethylene are used in reducing the speed of fast neutrons that are produced in nuclear fission interactions in reactors, in contrast to the neutron flux counter. By looking at the graph, we can see that the moderator function is effective in reducing the neutron speed and the reduction of the neutron flux in their counter. Also, in the absence of moderator, the neutron flux has been calculated and the results are displayed in the graph and compared. Work was done on different configurations of moderators and reflectors for the neutron flux from the WWR-K reactor. The results of the grant work will be applied in further research and recommended for application in science and technology related fields. The scientific and technical level of the work is at an appropriate height and in accordance with the achievements of modern science in these fields.

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توسعه پیکربندی های مختلف تعدیل کننده ها برای اندازه گیری فلکس نیوترون از ریاکتور WWR K

پوهنیار عبدالحمید حسن زاد[1] ، پوهنیار محمد طاهر شریفی[2]، دوکتور یرژان مخمژانوف[3]

[1,2] دیپارتمنت فزیک، پوهنځی تعلیم و تربیه مؤسسه تحصیلات عالی نیمروز.

[3] انستیتوت فزیک هسته‌ی، شهر الماتا، کشور قزاقستان.

ایمیل آدرس: hasanzadahamid@gmail.com

خلاصه

مطالعه انواع مختلف تعدیل کننده ها مانند پولی ایتلین وگرافیت در ریاکتور تحقیقاتی WWR K (Water- Water Reactor Kazakhstan) همیشه با مطالعه خواص مواد ساختمانی لازم برای ریاکتورهای انرژی هسته‌ای همراه خواهد بود. نیوترون های حرارتی در ریاکتور WWR K با تعدیل کننده پولی ایتلین-بورون، پولی ایتلین وهمچنان بدون تعدیل کننده. شمارش فلکس نیوترون صورت گرفته ونتایج آن در گراف ترسیم گردیده ومقایسه نتایج حاصل از مودل سازی کامپیوتری Gean4 درکنارآشکارساز SNM-15 نتایج درگراف ترسیم گردیده ونشان می‌دهد که آشکارسازها با مواد تعدیل کننده و بدون آن درگراف چه تفاوت وجود دارد. و بامشاهده گراف دیده می‌شود که شمارشگر درحالت بدون تعدیل کننده مقدارکمترفلکس نیوترون را نشان می‌دهد.

کلمات کلیدی: آشکارساز، تعدیل کننده نیوترون، مودل سازی کامپیوتری، نیوترون های حرارتی، Geant4، SNM-15.