PHYSICAL PARAMETERS OF AN INFINITE HOMOGENEOUS MEDIUM ($UO_2 + H_2O, D_2O, C$)

Bozorboev Shodlik G‘ayrat o‘g‘li

National Nuclear Research University “MEPhI” Russia, Moscow

Annotation. This article explores the physical parameters of an infinite homogeneous medium consisting of uranium dioxide (UO_2) mixed with moderators such as light water (H_2O), heavy water (D_2O), and graphite (C). Using the GETERA program for neutron-physics calculations, we determine the infinite multiplication factor (k_∞) and its components: fast fission factor (μ), resonance escape probability (ϕ), thermal utilization factor (θ), and reproduction factor (η). Results indicate that water achieves the fastest maximum k_∞, followed by heavy water and graphite. The study highlights the role of moderators in controlling chain reactions in nuclear reactors.

Keywords: nuclear fission, infinite multiplication factor, moderators, thermal utilization factor, fast fission factor, reproduction factor, resonance escape probability, GETERA program, neutron physics.

Annotatsiya. Ushbu maqola cheksiz bir xil muhitning fizik parametrlarini o‘rganadi, u uran dioksid (UO_2) va moderatorlar sifatida yengil suv (H_2O), og‘ir suv (D_2O) va grafit (C) aralashmasidan iborat. GETERA dasturi yordamida cheksiz ko‘paytirish koeffitsienti (k_∞) va uning komponentlari: tez bo‘linish faktori (μ), rezonansdan qutulish ehtimoli (ϕ), termal foydalanish faktori (θ) va ko‘paytirish faktori (η) aniqlandi. Natijalar shuni ko‘rsatadiki, suvda k_∞ eng tez maksimumga erishadi, keyin og‘ir suv va grafit keladi. Moderatorlar zanjir reaksiyasini boshqarishdagi roli ta’kidlanadi.

Kalit so‘zlar: yadro bo'linishi, cheksiz ko'payish omili, moderatorlar, issiqlikdan foydalanish koeffitsienti, tez bo'linish omili, ko'payish omili, rezonansdan qochish ehtimoli, GETERA dasturi, neytron fizikasi.

Аннотация. В данной статье исследуются физические параметры бесконечной однородной среды, состоящей из диоксида урана (UO_2) в смеси с замедлителями, такими как лёгкая вода (H_2O), тяжёлая вода (D_2O) и графит (C). Используя программу GETERA для расчётов в области нейтронной физики, мы определяем бесконечный коэффициент размножения ($k\infty$) и его компоненты: коэффициент быстрого деления (μ), вероятность выхода из резонанса (ϕ), тепловой коэффициент использования (θ) и коэффициент размножения (η). Результаты показывают, что вода достигает максимального значения $k\infty$ быстрее всего, за ней следуют тяжёлая вода и графит. В исследовании подчёркивается роль замедлителей в управлении цепными реакциями в ядерных реакторах.

ISSN 3030-3907

Ключевые слова: деление ядер, бесконечный коэффициент размножения, замедлители, тепловой коэффициент использования, коэффициент быстрого деления, коэффициент размножения, вероятность выхода из резонанса, программа GETERA, нейтронная физика.

1. Introduction

This work investigates the physical parameters of an infinite homogeneous medium composed of uranium dioxide (UO_2) combined with moderators such as light water (H_2O), heavy water (D_2O), and graphite (C), prepared through laboratory work with GETERA program. The relevance of this topic lies in determining the infinite multiplication factor (k_∞) for water, heavy water, and graphite, which is crucial for establishing reactor limits. Accurate selection of this factor ensures the safe operation of the reactor, while the GETERA program is utilized to determine the infinite multiplication factor and its four constituent factors.

The purpose of the work is to calculate the coefficients using the GETERA program, enabling the identification of the most convenient and effective moderator substances for use in reactors. This involves assessing which moderators are best suited based on their properties. The tasks include analyzing these coefficients to understand moderator properties, with the multiplication factor depending on the extent to which it is optimized. An improper selection of the multiplication factor could lead to reactor instability or explosion.

2. Experimental Methodology

This investigation utilizes the GETERA program to conduct neutron-physics calculations for determining the infinite multiplication factor (k_∞) and its four factors in an infinite homogeneous medium composed of uranium dioxide (UO_2) combined with moderators: light water (H_2O), heavy water (D_2O), and graphite (C). The GETERA code is designed to model physical cells for both fast and thermal neutrons in spherical, cylindrical, or plane geometries. For this study, a spherical geometry with a radius of r = 1 was assumed. The program employs the NAB-93 nuclear data library, which contains nuclear data for 15 nuclides distributed across 99 energy groups.

Four multiplicands formula: each multiplicand describes its own physical effect. Real advantage – very simple for analysis, very simple to remember.

$$k_\infty = \mu \cdot \varphi \cdot \theta \cdot \vartheta_{eff}$$

Calculations were performed to evaluate key parameters, including the infinite multiplication factor (k_∞), fast fission factor (μ), resonance escape probability (ϕ), thermal utilization factor (θ), and reproduction factor (η), as functions of the moderator-to-fuel ratio (C) and densities (rho_UO_2 and rho_moderator). The average number of neutron collisions required to slow down

ISSN 3030-3907

neutrons from an initial energy of E_1 = 2 MeV to E_2 = 0.025 eV was also computed for each moderator, highlighting their slowing-down efficiencies. These simulations provide insights into the optimal moderator selection for achieving a controlled chain reaction while ensuring reactor safety.

3. Results and Discussion

C	rho,UO_2	rho,H_2O	K	fi	teta	mu	nu_{eff}
1	0,013378	0,013378	1,2496	0,44379	1,000001	1,5411	1,8271
2	0,009556	0,019111	1,3664	0,60059	0,999986	1,2599	1,8058
3	0,007432	0,022296	1,4122	0,67771	1,00003	1,1732	1,7761
4	0,006081	0,024323	1,4304	0,72472	1,000067	1,131	1,745
5	0,005145	0,025726	1,4349	0,75686	1,000002	1,1061	1,714
6	0,004459	0,026756	1,4317	0,78042	1,000041	1,0896	1,6836
7	0,003935	0,027542	1,4237	0,79856	1,000053	1,0779	1,6539
8	0,00352	0,028164	1,4127	0,81305	0,999985	1,0692	1,6251
9	0,003185	0,028667	1,3999	0,82496	1,000039	1,0624	1,5972
10	0,002908	0,029082	1,3858	0,83496	1,000011	1,057	1,5702

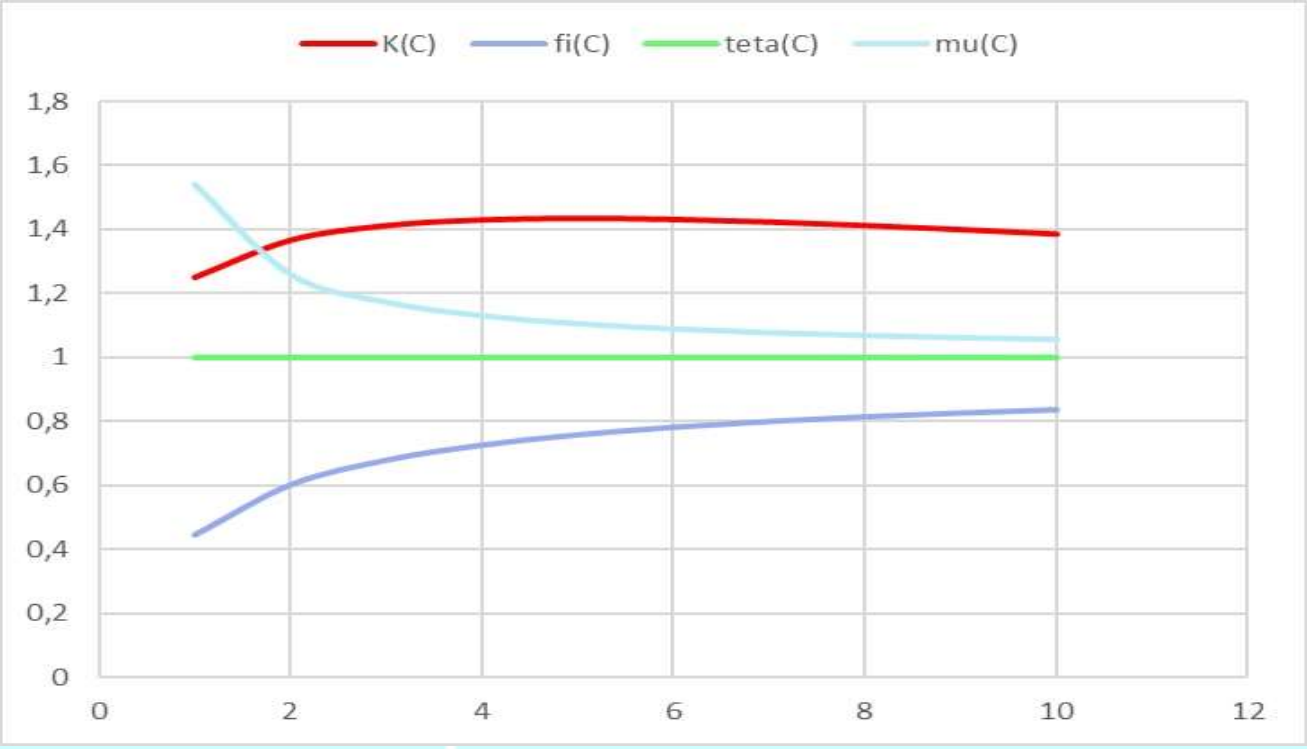


Figure 1. k_∞ vs C for UO_2+H_2O.

ISSN 3030-3907

C	rho, UO_2	rho, D_2O	K	fi	teta	mu	nu_{eff}
10	0,002883	0,028829	1,183	0,47809	0,999995	1,3221	1,8716
20	0,001541	0,030822	1,3523	0,62676	0,999969	1,1435	1,8869
30	0,001052	0,031548	1,4401	0,69728	0,999935	1,0915	1,8923
40	0,000798	0,031925	1,4956	0,7398	1,000032	1,0669	1,8948
50	0,000643	0,032155	1,5347	0,76891	0,999959	1,0527	1,8961
60	0,000539	0,03231	1,564	0,79034	0,999939	1,0434	1,8967
70	0,000463	0,032422	1,5871	0,80692	1,000026	1,0368	1,897
80	0,000406	0,032507	1,6058	0,82025	0,999996	1,032	1,897
90	0,000362	0,032573	1,6214	0,83129	0,999991	1,0283	1,8968
100	0,000326	0,032626	1,6347	0,84064	1,000003	1,0253	1,8966

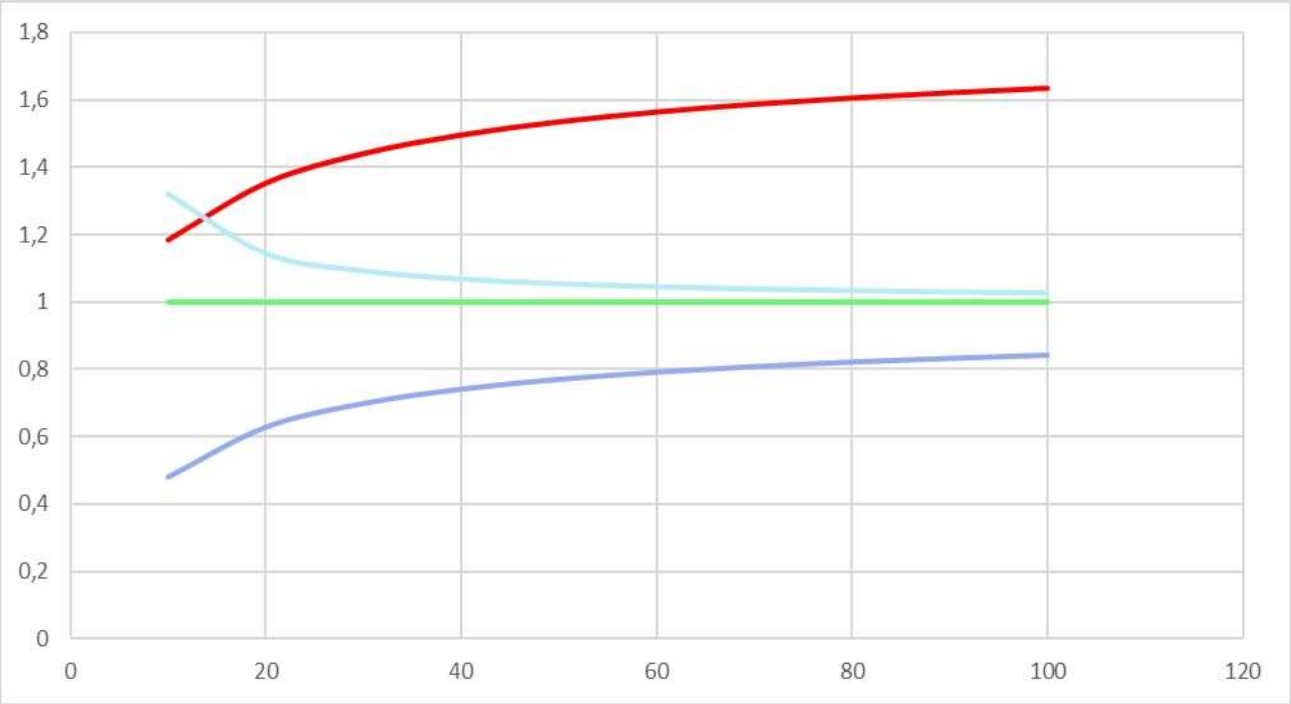


Figure 2. k_∞ vs C for UO_2+D_2O.

C	rho, UO_2	rho,C	K	fi	theta	mu	nu_{eff}
100	0,000775	0,077477	1,0612	0,41097	1,000052	1,2588	2,0512
200	0,000394	0,078847	1,3304	0,56054	1,00001	1,1036	2,1506
300	0,000264	0,079315	1,4771	0,63653	0,999954	1,0634	2,1823

ISSN 3030-3907

400	0,000199	0,079551	1,5672	0,68476	0,999996	1,0454	2,1893
500	0,000159	0,079693	1,6258	0,71902	1,000012	1,0354	2,1838
600	0,000133	0,079788	1,666	0,74499	0,999976	1,029	2,1733
700	0,000114	0,079856	1,6938	0,76578	1,000026	1,0246	2,1587
800	9,99E-05	0,079907	1,7124	0,78267	1,000073	1,0214	2,1419
900	8,88E-05	0,079947	1,7249	0,79701	0,999981	1,019	2,1239
1000	8E-05	0,079979	1,7327	0,80914	0,999956	1,0171	2,1055

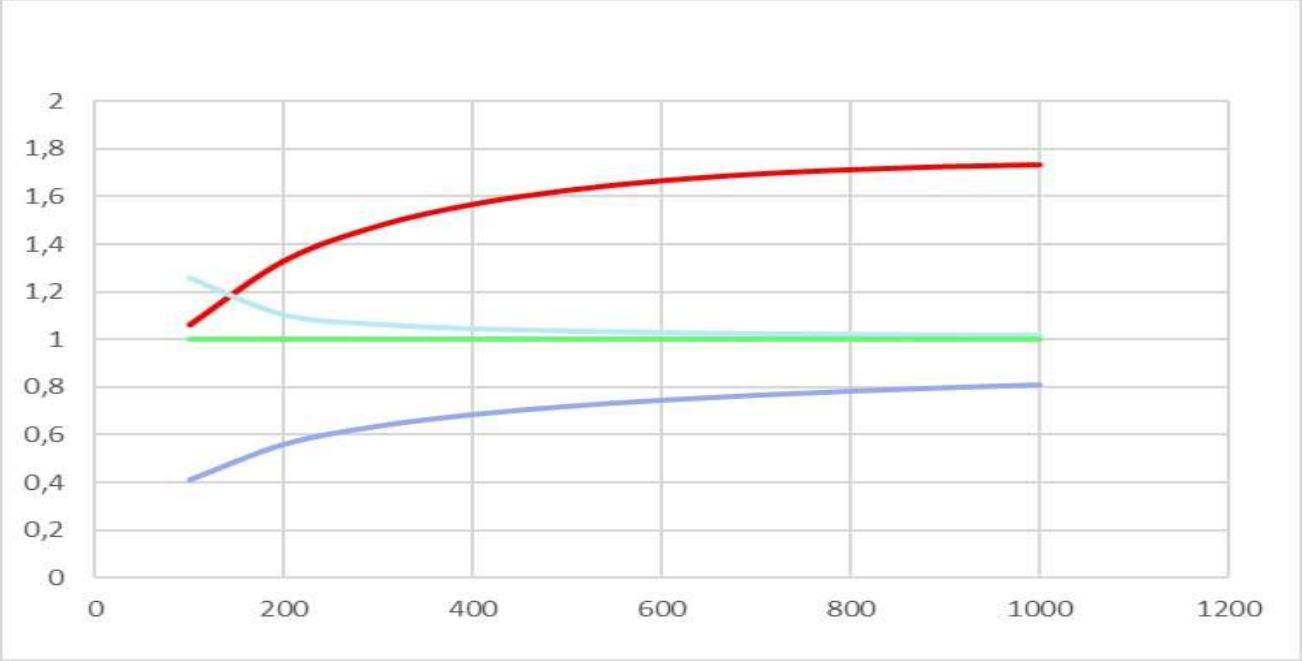


Figure 3. k_∞ vs C for UO_2+C.

4. Conclusion

The analysis reveals that light water (H_2O) provides the best slowing-down performance among the tested moderators, achieving the fastest maximum effective multiplication factor (k_{eff}) due to its optimal collision efficiency for reducing neutron energy from 2 MeV to 0.025 eV, requiring approximately 19 collisions on average. Heavy water (D_2O) demonstrates relatively slower slowing-down with around 5.7-35.7 collisions, while graphite (C) exhibits the slowest rate, necessitating 15.3-115.3 collisions for similar energy reduction. These differences underscore H_2O as the superior moderator for rapid neutron thermalization in UO_2-based infinite homogeneous media, followed by D_2O and C, with optimal moderator-to-fuel ratios (C) varying in units for H_2O, decimals for D_2O, and hundreds for C under spherical geometry (r=1).

ISSN 3030-3907

To enhance reactor design, it is recommended to prioritize H_2O for applications requiring quick chain reaction control, while exploring hybrid moderator configurations to balance slowing-down efficiency with safety margins.

REFERENCES

1. Kenneth S. Krane Oregon State University INTRODUCTORY NUCLEAR PHYSICS.
2. Savander V.I. Uvakin M.A. PHYSICAL THEORY NUCLEAR REACTORS Part I Moscow 2007.
3. Lamarsh, J.R. Introduction to Nuclear Reactor Theory. Addison-Wesley, 1966.
4. Duderstadt, J.J., Hamilton, L.J. Nuclear Reactor Analysis. John Wiley & Sons, 1976.
5. Glasstone, S., Sesonske, A. Nuclear Reactor Engineering. Van Nostrand Reinhold, 1994.

ISSN 3030-3907