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SOVIET BERYLLIUM PHYSICS REACTOR (BRF)

Review of Soviet Literature

AID Work Assignment No. 16

Aerospace Information Division

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FOREWORD

This report provides a detailed description of the Soviet beryllium Physics Reactor (BRF), which was designed to investigate the possibility of using beryllium as a neutron moderator in nuclear reactors. Background information, general construction and control details, and the physical parameters obtained for the reactor are presented. The report has been prepared in conformance with AID Work Assignment No. 16, and is based on Soviet open literature available at the Aerospace Information Division and the Library of Congress. Any further information concerning this reactor will be published in the form of supplements to this report, as soon as it becomes available. A list of the references cited accompanies the text. Library of Congress call numbers are included at the end of the source entry when the source is available at the Library of Congress.

THE BRF REACTOR

1. Background

In addition to graphite and heavy and light water, it should also be possible to use beryllium as a neutron moderator in nuclear reactors.

In order to study the physical parameters of a reactor having a beryllium moderator, a Beryllium Physics Reactor (BRF) with a beryllium-metal moderator was put into operation in 1954 at the Atomic Electric Station of the Academy of Sciences USSR. [1]

The objectives of the study included the determination of experimental values of critical masses and lattice multiplication parameters, investigation of the extent to which the $Be^9(n, 2n)Be^8$ reaction contributes to the magnitude of the effective multiplication factor, and a study of the effect on the reactor kinetics of delayed photoneutrons formed in the reaction $Be^9(\gamma, n)Be^8$. The results obtained provided information which can be useful for improving design methods for small reactors with beryllium moderators. [2]

2. General Construction[1]

The core of the BRF is made of beryllium blocks measuring 160 mm x 160 mm x 40 mm each, which form a cylinder 960 mm high and 1040 mm in diameter, having a total weight of 1200 kg. [1] This beryllium cylinder is mounted on a thin steel plate 1.5 m above the floor in the center of a large laboratory hall. This made it possible to eliminate the effect of scattered neutrons when critical assemblies without a reflector were being studied. [2] The density of the beryllium is 1.78 g/cm^3. The core has vertical channels which form a rectangular lattice with 107 x 64 mm pitch. There is a channel 17 mm in diameter in the center of each elementary cell. This central channel is surrounded by six channels 14.5 mm in diameter, arranged on a circle with a 20 mm radius. In addition, the core contains 108 horizontal channels 31 mm in diameter. [1]

The fuel elements are of the tubular type. The annulus of each fuel element is formed by two thin-walled coaxial steel tubes, 13.4 x 0.2 mm and 9.0 x 0.4 mm in diameter, which are filled to a height of 960 mm with 10% enriched U_3O_8 powder. Each fuel element contains 2.4 g of U_3O_8. The central channels and the space inside the inner tubes of the fuel elements are used to study the effect of water on the multiplication parameters of the reactor. [1]

[1]No illustrative material could be found.

3. Control

The control of the reactor is accomplished by means of two cadmium rods 8.2 mm in diameter and 960 mm long. The reactor is also equipped with eight cadmium safety rods of the same dimensions. [1]

The activity level in the reactor is monitored by boron proportional counters and ionization chambers. A concrete wall 1 m thick protects the personnel from radiation. [1]

4. Physical Parameters

Investigations of Critical Masses

Because of the dimensions of the beryllium cylinders and the use of the above described fuel elements, dimensions and critical mass values could only be obtained for those assemblies in which the numerical ratio of Be nuclei to U^{235} nuclei (C_{Be}/C_5) was in the range from 1777 to 3112. [2]

Critical experiments were conducted for this range of concentrations, using the following three variants of critical assemblies: 1) with no water in either core or reflector; 2) with water in the fuel elements only (in which case the number of H nuclei per U^{235} nucleus was constant and equal to 76); and 3) with water in both the fuel elements and the horizontal channels. The water in the horizontal channels was contained in aluminum tubes 30 x 1 mm in diameter. [2]

The numerical ratio of Be nuclei to H nuclei varied somewhat (from 7.8 to 11) as C_{Be}/C_5 changed from 3112 to 2080.

The critical assemblies were studied without any reflector, with a beryllium reflector, and with a reflector composed of a beryllium and water mixture. [2]

The dependence of critical mass on C_{Be}/C_5 for all three types of nonreflected critical assemblies is shown in Fig. 1. The experimental results indicate that in the case of a thermal reactor, ratios of $C_{Be}/C_5 < 3112$ are not optimal with regard to critical mass. Thus, when an additional water reflector was introduced into the core of the thermal reactor, the critical masses were sharply reduced (curves 2 and 3, Fig. 1). [2]

Figure 2 shows the dependence of the critical dimensions of nonreflected assemblies on the C_{Be}/C_5 ratios. The dimensions are expressed in terms of a geometrical (buckling) parameter, κ^2, computed from the expression

$$\kappa^2 = \left(\frac{2{,}405}{R + 0{,}71\lambda_{tr}}\right)^2 + \left(\frac{3{,}14}{H + 2 \cdot 0{,}71\lambda_{tr}}\right)^2.$$

where R is the radius of the nonreflected critical assembly (constant and equal to 52 cm) for all assemblies, h is the height of the critical assembly (variable), and λ_{tr} is the transport mean free path for neutrons. [2]

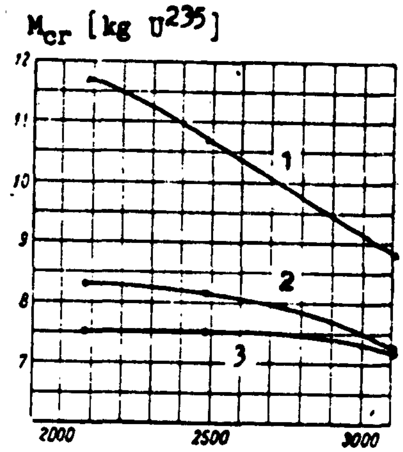

Fig. 1. Dependence of critical mass on C_{Be}/C_5 for nonreflected assemblies of types 1, 2, and 3 [2]

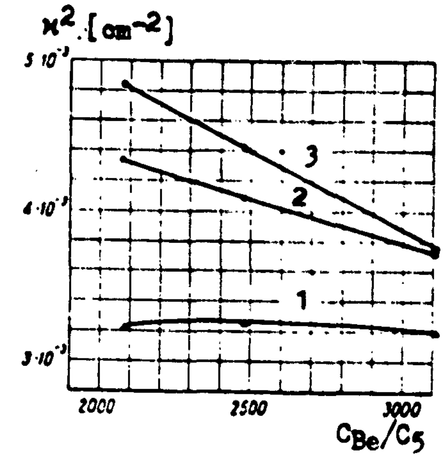

Fig. 2. Dependence of geometrical parameter κ^2 on C_{Be}/C_5 for nonreflected critical assemblies of types 1, 2, and 3 [2]

The critical masses and dimensions of the assemblies were also determined for the same values of C_{Be}/C_5, but this time with the addition of reflectors made of beryllium and a beryllium and water mixture. In this case the reactor's height h was constant and equal to 96 cm, while the radius of the core varied. The radius of the beryllium cylinder was constant and equal to 52 cm. Despite the fact that reflector thickness varied with the value of C_{Be}/C_5, the efficiency of the beryllium and of the beryllium and water reflectors could be experimentally evaluated. [2]

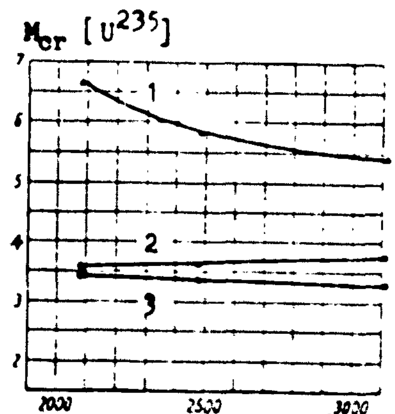

Fig. 3. Dependence of critical mass on C_{Be}/C_5 for assemblies of types 1, 2, and 3 with reflectors [2]

The dependence of critical mass (M_{cr}) on the values of C_{Be}/C_5 is shown for assemblies of types 1, 2, and 3 with reflectors in Fig. 3. It is noteworthy that the water in the horizontal channels reduces the efficiency of the reflectors, which in turn causes a slight increase in the critical mass of the corresponding assembly (curve 3, Fig. 3). Further experimental results are given in Tables 1, 2, 3, and 4 on the next two pages. [2] [Text resumes on p. 6.]

Table 1. Results of experimental determination of reflector savings [2]

R - radius of critical assembly without reflector; d - reflector thickness; δ - reflector saving

C_{Be}/C_5	Critical assembly type 1, cm			Critical assembly type 2, cm			Critical assembly type 3, cm		
	R	d	δ	R	d	δ	R	d	δ
2080	36.5	15.5	14.7	26.2	25.8	15.5	26.8	25.2	12.1
2480	37.5	14.5	13.4	28.4	23.6	15.0	28.2	23.8	13.0
3112	40.4	11.6	11.1	31.5	20.5	15.7	33.7	18.3	12.3

Table 2. Critical masses for various combinations of reactor parameters (apertures in beryllium cylinder filled with graphite slugs; end reflectors absent) [2]

C_c - beryllium and water mixture.

Number of fuel elements per cell	Thickness of side reflector cm	Radius of core, cm	Critical mass, kg U^{235}	C_{Be}/C_5	C_c/C_5	Height of reactor, cm
4	11.6	40.4	5.46	3112	463	96
4	0	52.0	8.78	3112	463	90
5	14.5	37.5	5.86	2486	337	6
5	0	52.0	10.70	2486	337	88
6	15.5	36.5	6.66	2075	255	96
6	0	52.0	11.70	2075	255	89
7	14.4	37.6	8.26	1777	113	96

Table 3. Critical masses for various combinations of reactor parameters (apertures in beryllium cylinder filled with graphite slugs; central tubes of fuel elements filled with water; end reflectors absent) [2]

C_H - hydrogen nuclei.

Number of fuel elements per cell	Thickness of side reflector, cm	Radius of core, cm	Critical mass, kg U^{235}	C_{Be}/C_5	C_c/C_5	C_H/C_5	Height of reactor, cm
4	20.5	31.5	3.31	3112	401	72	96
4	0	52.0	7.3	3112	401	72	74
5	23.6	28.4	3.36	2486	273	72	96
5	0	52.0	8.16	2486	273	73	64
6	25.8	26.2	3.42	2075	190	72	96
6	0	52.0	8.30	2075	190	72	63
7	27.4	24.6	5.53	1777	113	72	96

Table 4. Critical masses for various combinations of reactor parameters (apertures in beryllium cylinder filled with graphite slugs; center tubes of fuel elements and horizontal channels in beryllium cylinder filled with water; end reflectors absent) [2]

Number of fuel elements per cell	Thickness of side reflector, cm	Radius of core, cm	Critical mass, kg U^{235}	C_{Be}/C_5	C_c/C_5	C_H/C_5	Height of reactor, cm
4	18.3	33.7	3.78	3112	202	242	96
4	0	52.0	7.20	3112	202	242	73.7
5	23.8	28.2	3.62	2486	115	208	96
5	0	52.0	7.55	2486	115	208	62
6	25.2	26.8	3.60	2075	58	186	96
6	0	52.0	7.51	2075	58	186	57
7	26.9	25.1	3.69	1777	0	170	96

Determination of the Multiplication Factor

Measurements were made to determine the U^{238} resonance escape probability, the distribution of neutrons across the cell, and the cadmium ratio (R^{5}_{cd}) for U^{235}. The measurements were conducted for critical assemblies 1 and 2 with a C_{Be}/C_5 ratio of 2080. These measurements made possible the evaluation of the accuracy of thermal utilization computations and the determination of neutron multiplication due to the reaction Be^9(n, 2n)Be^8.

The results show the thermal utilization calculations to have an accuracy of 0.5%, provided all absorbers are homogeneously mixed throughout the cell. [2]

Resonance escape probability φ was determined by measuring the cadmium ratio for U^{238}, using a ring foil placed in the section of a fuel element. [2]

The effect of the Be^9(n, 2n) Be^8 reaction was determined by analyzing the neutron balance. On condition that the age theory is valid for a beryllium reactor, the following expression can be written for a critical reactor:

$$1 + L^2\varkappa^2 = \nu_{эфф}\theta, \varphi, \mu, \varepsilon, \eta, e^{-\varkappa^2\tau},$$

where L^2 is the square of the thermal neutron diffusion length in the core; $\varkappa^2$ is buckling; $\nu_{эфф}$ is the average number of secondary neutrons per capture in U^{235}; θ is the fraction of thermal neutrons absorbed in U^{235}; φ is the resonance escape probability; μ is a factor taking into account non-fission capture taking place in the U^{235} and construction materials in the intermediate region of the reactor neutron spectrum; ε is the multiplication factor (ε = 1); τ is the age of thermal neutrons; and η is a factor taking into account the Be^9 (n, 2n) Be^8 reaction's share of the effective multiplication factor.

Accordingly, $$\eta = \frac{(1 + L^2\varkappa^2)\, e^{\varkappa^2\tau}}{\nu_{эфф}\theta\varphi\mu}.$$

The lattice parameter values obtained for beryllium reactors of types 1 and 2 are given in Table 5. [2]

Table 5. Parameters for beryllium reactor lattice. [2]

$\frac{C_{Be}}{C_5}$	L^2, cm²	τ, cm²	$\varkappa^2$, cm⁻²	φ	θ	$\nu_{эфф}$	R^8_{Cd}	μ	η
Type 1									
2080	24	148	$3{,}22 \cdot 10^{-4}$	0,94	0,825	2,08	6,67	0,96	1,12
Type 2									
2080	21	101	$4{,}35 \cdot 10^{-4}$	0,95	0,8[illegible]	2,08	7,14	0,9[illegible]	1,10

Study of the Effect of Delayed Photoneutrons
on the Kinetics of a Beryllium-Moderated Reactor

Beryllium has a low (1. 63 Mev) photoneutron threshhold. For this reason the use of beryllium as a moderator in nuclear reactors results in the production of additional neutrons by the $Be^9(\gamma, n) Be^8$ reaction. The hard γ-quanta which cause the reaction may be formed by 1) fission of uranium nuclei, 2) β-decay of some uranium fission fragments, or 3) absorption of neutrons by constructional materials. Photoneutrons which are produced by prompt hard γ-quanta resulting from the fission of uranium nuclei or the absorption of neutrons by nuclei of construction materials behave in the same way as prompt fission neutrons. [2]

Similarly, photoneutrons which are produced by the interaction of delayed hard γ-quanta and Be^9 nuclei behave like ordinary delayed neutrons, from which they are terminologically distinguished by calling them delayed photoneutrons. [2]

During constant power level operations of the reactor, the contribution of delayed neutrons and photoneutrons to the neutron flux is small; when the reactor is shut down, however, the contribution of delayed neutrons and photoneutrons becomes decisive and the principal determinant of the presence of neutrons in the reactor. [2]

After the reactor is shut down, the neutron radiation intensity drops according to the law of the sum of exponents. Study of the curves of the neutron intensity decay makes it possible to determine the yields and halflives of the delayed neutrons and photoneutrons present in the reactor. For this purpose, the drop in neutron density was measured with absorbing rods. The neutron-density drop curves were resolved into components by the use of specially developed analytical methods. This was done twice, once taking into account the daughter nuclei, and once disregarding them. [2]

This analysis of the neutron-intensity drop curves revealed 12 to 14 groups of delayed neutrons. The results obtained are given in Tables 6 and 7, in Figures 4 and 5, and in Figures 6, 7, and 8.

Table 6 gives data obtained by resolution of the curves assuming the quantum producing the given photoneutron groups to be directly emitted by the primary fission fragment.

Table 7 gives data obtained taking account of the daughter nuclei, which emit the γ -quanta producing the corresponding photoneutron groups. This table, supplemented by the inclusion of the three most short-lived groups (not determined in this experiment), can be recommended for reactors of the type under study. [2]

The yields of the delayed groups found were standardized on the basis of the known yield of an ordinary delayed group having a mean life τ = 31.7 sec and a yield β = 0.00166. [2] [Text resumes on p. 12.]

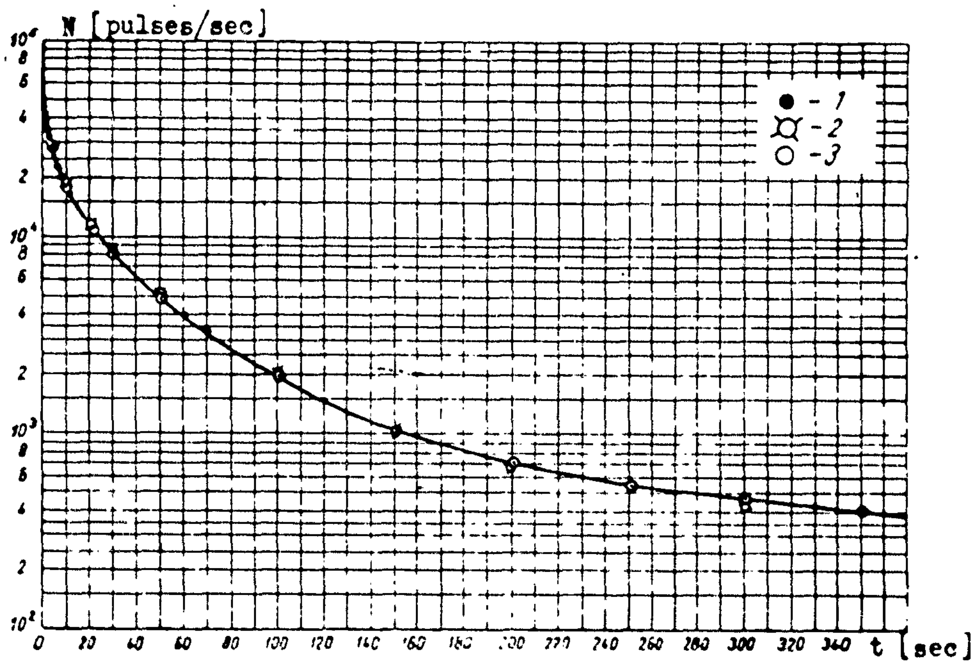

Fig. 4. Neutron intensity drop after shutdown of a reactor with beryllium moderator, following an hour's operation at capacity. Negative reactivity introduced by absorbing rods = 0.068 [2]

1 - experimentally determined points; 2 - points calculated from parameters of delayed neutron groups determined from data in Table 6; 3 - points calculated from parameters of delayed neutron groups determined from data in Table 7. (Curve continued in Fig. 5)

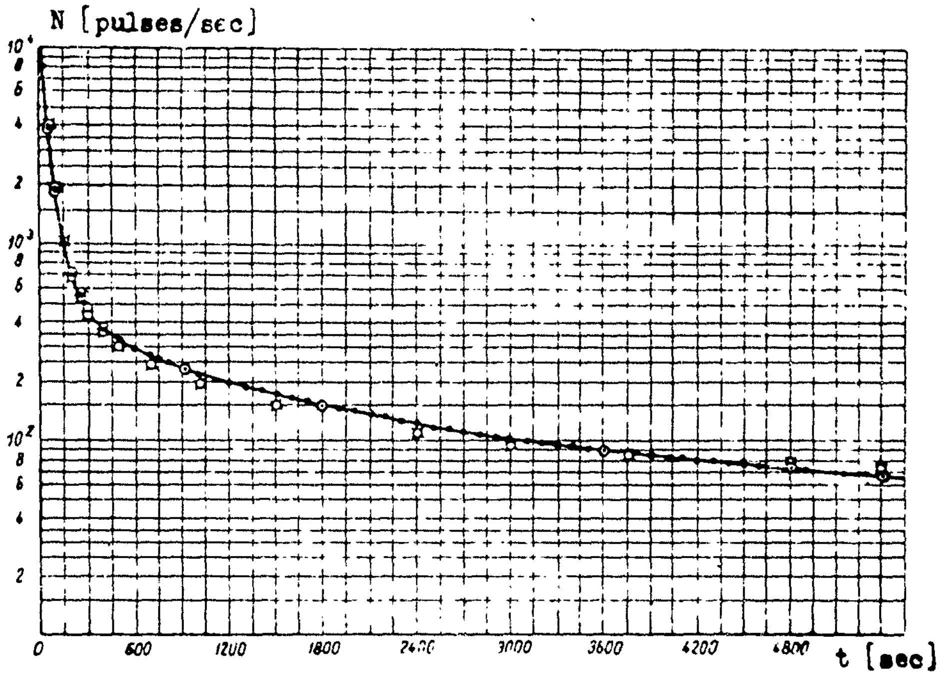

Fig. 5. Neutron intensity drop curve continued from Fig. 4 [2]

Table 6. Delayed photoneutrons [2]

Group No.	Mean Lifetime, τ_i	Yield, $\beta_i \cdot 10^5$
1	3814.0 min	0.0628
2	576.0 min	0.694
3	279.0 min	0.479
4	158.0 min	0.894
5	93.0 min	1.15
6	28.9 min	1.72
7	9.44 min	2.63
8	269.1 sec	1.51
9	80.7 sec	35.7
10	31.7 sec	166.0
11	6.50 sec	233.0
12	3.12 sec	14.3

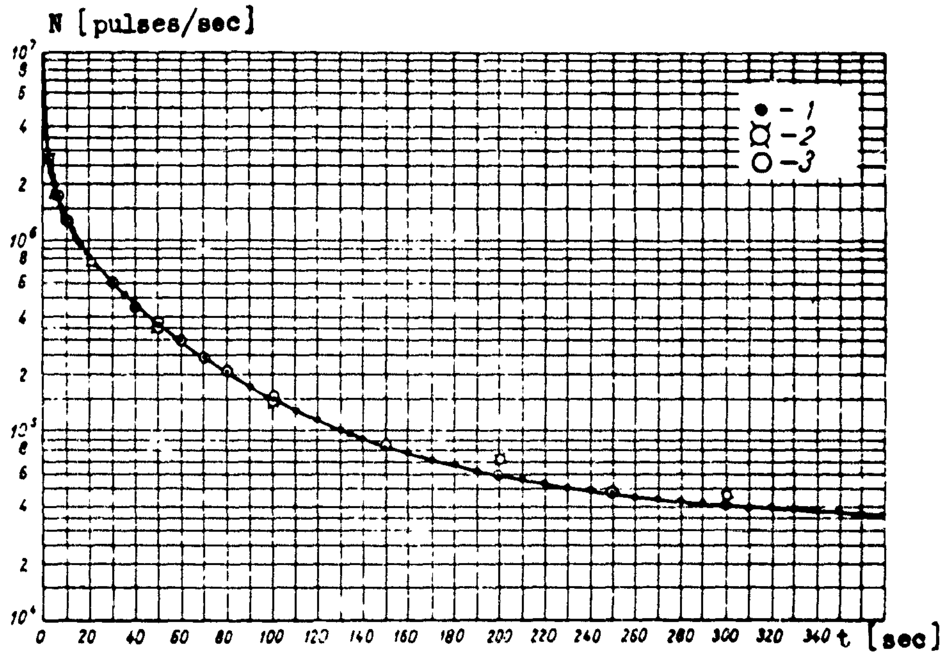

Fig. 6. Neutron intensity drop after shutdown of a reactor with beryllium moderator, following 7 hours' operation at capacity. Negative reactivity introduced by absorbing rods = 0.052 [2]

1 - experimentally determined points; 2 - points calculated from parameters of delayed neutron groups determined from data in Table 6; 3 - points calculated from parameters of delayed neutron groups determined from data in Table 7. (Curve continued in Figs. 7 and 8)

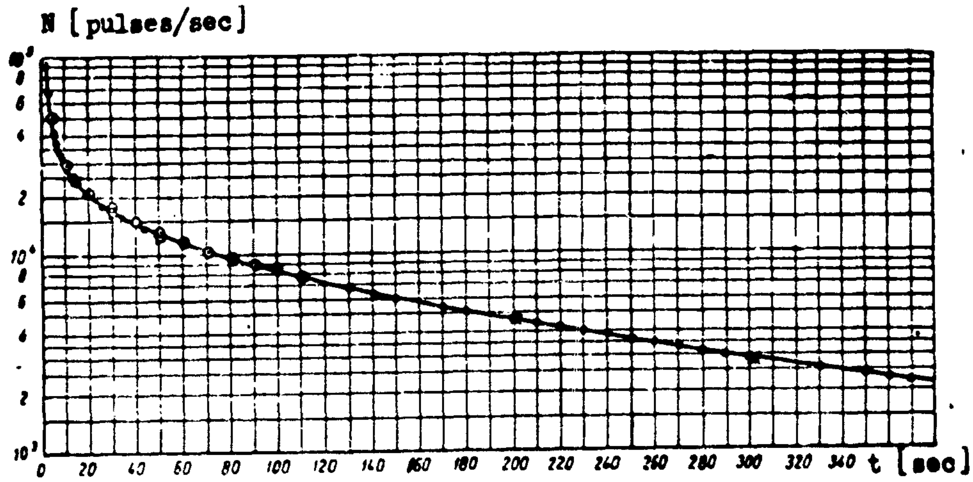

Fig. 7. Neutron intensity drop curve continued from Fig. 6 [2]

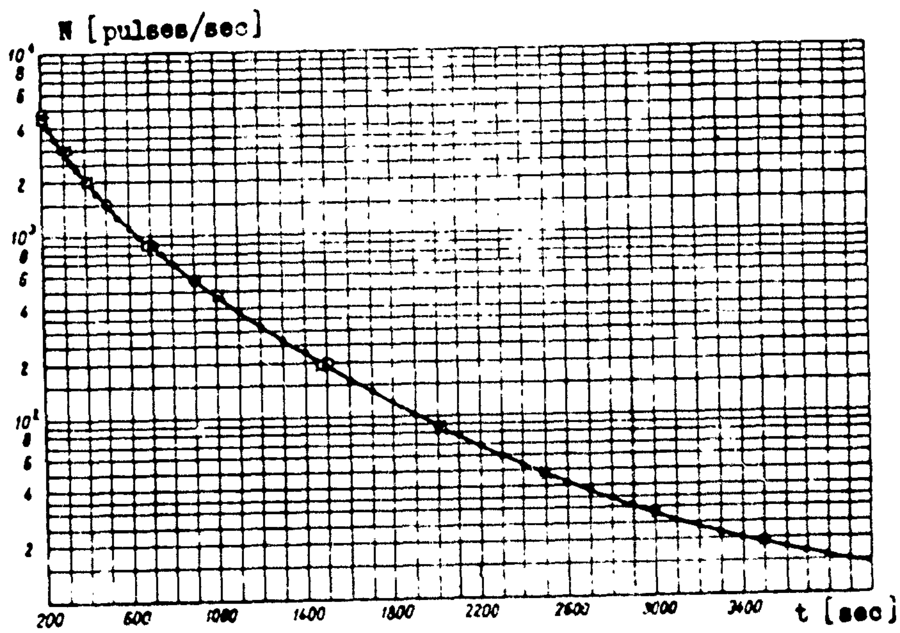

Fig. 8. Neutron intensity drop curve continued from Fig. 7 [2]

Table 7. Delayed photoneutrons [2]

Fission fragments determining the given neutron group	Mean Lifetime, τ_i	Yield, $\beta_i \cdot 10$
Te^{132} -- J^{132}	112 h, 3.46 h	0.034
Te^{131*} -- Te^{131}	43.3 h, 36.1 h	0.029
J^{135}	9.67 h	0.700
Kr^{88} -- Rb^{88}	4 h, 25.7 min	0.665
Br^{87} -- Kr^{87}	80.2 sec, 1.87 h	1.53
Se^{84} -- Br^{84}	3.46 min, 47.6 min	0.29
not determined	22.5 min	2.82
not determined	9.4 min	0.56
not determined	5.4 min	2.28
J^{136}	124.0 sec	1.66
Br^{87}	80.3 sec	34.2
not determined	43.0 sec	4.24
J^{137}	31.9 sec	166
not determined	6.5 sec	233
not determined	2.19 sec	241
not determined	0.62 sec	85
not determined	0.07 sec	25

Incorporation of the short-lived groups (not determined) which may be considered identical to those in ordinary reactors, gives a total yield of β = 0.0081 for Table 6 and β = 0.0080 for Table 7. [2]

The total yield was also determined from the sudden drop in the intensity of prompt neutrons during the initial moment after insertion of the absorbing rods. For this purpose it was necessary to determine the negative reactivity introduced, the counting rates at the given power level, and the value of the sudden neutron intensity drop. Operation of the reactor at capacity for 7 hours and the introduction of a negative reactivity of ρ = 0.0520 resulted in a yield β = 0.0082, while a negative reactivity of ρ = 0.068 resulted in a yield β = 0.0083. [2] These values are in good agreement with the values (β = 0.0080 and β = 0.0081) obtained by the resolution of curves cited above.

5. Comments

Soviet scientists had already conducted a number of investigations dealing with the properties of beryllium and beryllium oxides as neutron moderators before the BRF reactor was put into operation in 1954.

An investigation of the effective cross-sections for thermal neutron capture and the measurement of slowing-down length and diffusion length in beryllium, conducted by A. K. Krasin, I. G. Morozov, L. A. Gerasova, and O. V. Kanayev from 1948 to 1952, is reported in source. [3].

The results of this investigation led to the following conclusions:

1) Metallic beryllium has a very small neutron absorption cross-section $\sigma_c = (6.0 \pm 1.2) \cdot 10^{-27}$ cm^2.

2) The mass production of high purity beryllium (having total impurities of less than 1 mbarn per beryllium nucleus) presents serious technological difficulties. However, beryllium with total impurities of 2 to 3 mbarn per nucleus can be produced in large quantities. This beryllium has an absorption cross-section $\sigma_c(Be) = (9.0 \pm 1.2) \cdot 10^{-27}$ cm^2 and can be used in thermal reactors. [3]

The problem of the practical use of beryllium in the construction of an actual reactor can only be solved after completion of the study of the physico-mechanical and corrosive properties of beryllium under conditions similar to actual reactor operating conditions. [3]

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