E16-2002-79

V. V. Golikov, E. N. Kulagin, E. P. Shabalin

DOSE RATES NEAR WATER MODERATOR OF THE **IBR-2** REACTOR: EXPERIMENT AND ANALYSIS

1. Introduction

For the URAM-2 Project [2] (study of radiation effects in cold moderator materials) reliable data on absorbed dose rates in metals and hydrogeneous materials are quite necessary to know. Until recently, an estimate for the absorbed dose in hydrogenous materials due to scattering of fast neutrons has only been made based on the knowledge of neutron flux and spectra which were measured by the activated foils method. It is really not precise estimate, and a direct measurement of the dose rates including those of by gamma-rays absorption was needed.

2. Methods of measurements

Three methods have been applied:

- Calorimetric measurements;
- Radiolytic gas production method;
- Estimates from the knowledge of neutron flux and spectra.

2.1. The calorimetric measurements have been performed in a common use way by a sample temperature recording versus time at a constant radiation field (constant power of the reactor). Samples were kept inside an evacuated chamber. Row experimental data were processed accounting for a loss of a heat due to, mostly, thermal radiation. These losses have been estimated by analyzing of the samples temperature records after the reactor was switched off. Copper and light water in a stainless steel capsule were chosen to be samples.

2.2. Radiolytic gas production in a polythelene film was estimated by recording a gas pressure inside isolated space. The gas production factor is a referenced value - $3.1 \cdot 10^{-7}$ mol/J of the absorbed energy [3]. This value has been checked for the given sample (a film of the low density polythelene of 0.135 mm thickness) at a known gamma-radiation field from a Cs-source, and it appeared to be the same as the referenced one in the range of the experimental error about 5%.

2.3. **Neutron flux and neutron spectra** were measured by activation foils method. To estimate the fast neutron flux, seven isotopes were used: Ni, Fe, Ti (three isotopes), Al, and In; Cu and Cr were used for determining the thermal neutron flux, and for a draft estimate of the resonance neutron spectra. Some samples were wrapped into Cd foils. A restoring method of fast neutron spectra is described in [4].

3. Description of the irradiation rig

The cut-away section of the irradiation evacuated chamber is shown in Fig.1,

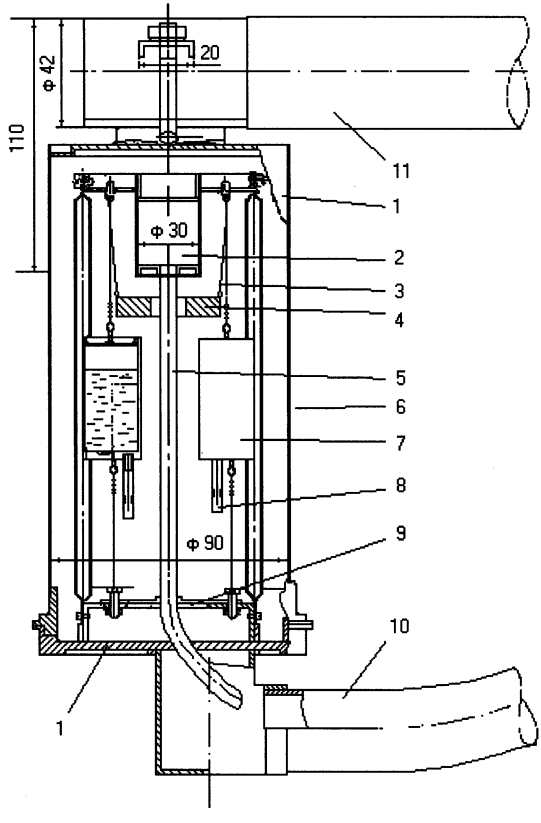

Fig. 1 Cut-away section of the evacuated chamber with the samples; notation see in the text of the paper.

and a cross-section of the chamber with surroundings is shown in Fig.2.

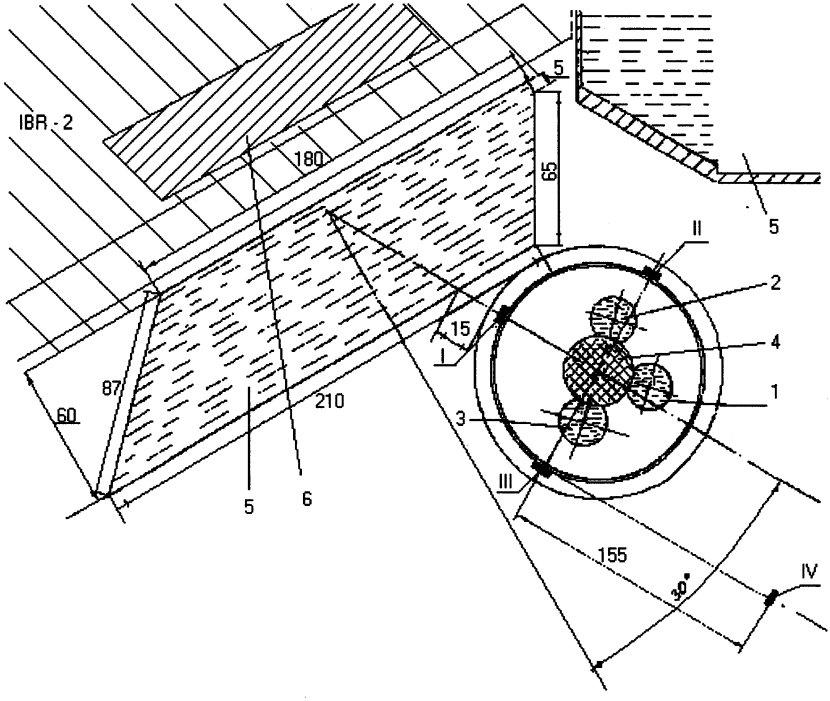

Fig. 2 Horizontal section of the evacuated chamber with surroundings, lay-out of the samples. I, II, III, and IV – sites of activation foils, 1, 2, and 3 – capsules with water, 4 – capsule with polyethylene, 5 – water moderator of the reactor, 6 – block KO-1.

Inside the vacuum jacket Fig. 1 (*1*) there are:

- the evacuated capsule with a polythelene film (weight 5.99 g) inside it (*2*) and the copper tube (*5*) holding it and transferring radiolytic gas to a pressure meter which is located about 9 m distance in the protected area.

- A copper ring (*4*), 89.4 g of weight, suspended onto three thin (0.2 mm) Ni-Cr wires (*3*); two "copper-constantan" thermocouples are welded into the ring.
- Three small, vacuum-tighten barrels (*7*) of stainless steel filled with distilled water. They are suspended onto thin wires as the copper ring does, and located in circular way around the axis of the vacuum jacket (see in Fig.2). Their temperatures are measured with thermocouples welded into the necks (*8*) of the barrels. All thermocouple wires are passed through the long tube (*10*) which also serves both for pumping out air from the vacuum jacket and as a holder of the whole construction alongside the upper holding tube (*11*). Masses of steel and water in each barrel are equal – (14.4±0.1) g.
- The steel framework (*9*) serves for fastening the wires which support the copper ring and the barrels.
- At the outer side of the jacket four sets of foils for activation (pos. *6* in Fig.1 and pos. I-IV in Fig.2) were fixed on in such a way so that to take them out from the jacket after an irradiation as soon as possible without radiation loads onto the staff.

The irradiation rig with the holding tubes *10* and *11*, 2.7 m length, is fastened to the existing construction composed of a biological shield on the cart and engineering environments (pumps, valves, measuring instruments). Thermocouples and pressure meter readings were stored in a computer file with a periodicity of once per 27 sec.

4. Experiment, analysis and results

Only one run of irradiation was performed. Control rods at the side of channel $N^{0}3$ were in position 340 mm (KO-1) and 85 mm (PO). Grooved water moderator was installed instead of cold moderator. Power of the reactor has been risen linearly in time from 27 kW and kept constant at 243 kW for 2.5 hours. Then the reactor power was decreased down to zero in a time so short as 12 min. The temperatures of the samples were permanently recorded onto PC. Some readings of thermocouples one can see in Fig. 3. It is clear that thermal losses should be accounted

for during the data processing because the temperatures during the heating are not linear in time as it would be for good thermal insulation conditions. Only at the initial stage of the heating up to several degrees it is acceptably to neglect this correction.

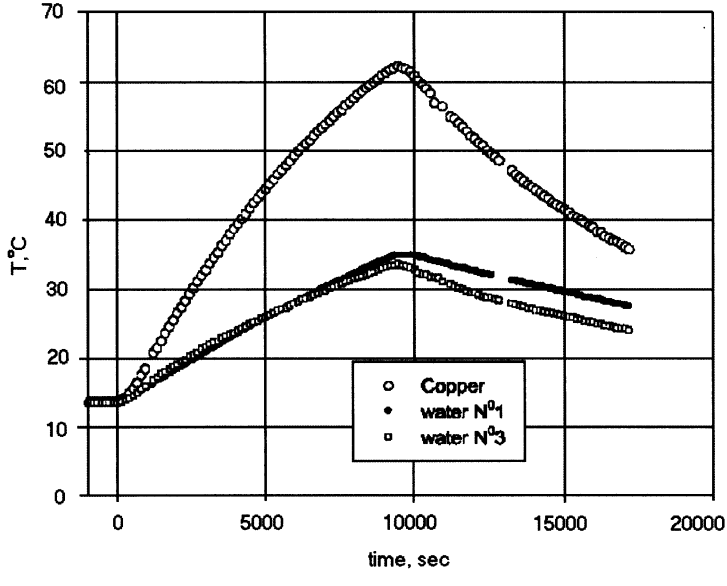

Fig. 3 Records of the sample temperatures

Then, corrections for the heat losses were done by two methods:

1. Assuming the Newton law of cooling, that is, a heat loss is always linear proportional to the difference between the temperature of the sample and surroundings. Then the heat production in the sample at i-th moment of time Q_i may be restored from the relation:

$$Q_i = C_p \cdot M \cdot \left(\frac{\partial T_+}{\partial t_i} - \frac{\partial T_-}{\partial t_k} \right)$$

where C_p is a specific heat of a material of the sample (which is temperature dependent), M is a mass of the sample, and the terms inside the brackets are the time derivatives of the sample temperature at the i-th instant of heating

and at the k-th instant of cooling corresponding the same temperature of the sample, respectively. For the capsules with water

$$c_p \cdot M = c_{psteel} \cdot M_{steel} + c_{pwater} \cdot M_{water},$$

evidently. Real quantity of Q was considered to be as an averaged over the whole range of i and k available from the experiment.

2. Assuming that

$$Q = c_p \cdot M \cdot \left(\frac{\partial T_+}{\partial t} \right)_{max}$$

where the maximum of temperature derivatives is an extrapolated value of the "time derivative of temperature versus temperature" function, down to the initial temperature (14 ^{0}C in the case); it reflects the certain fact that heat losses are negligible when temperature difference between a sample and surroundings is close to zero.

Method N^o 1 gave a little bit lower values of Q than method N^o 2, up to 10%. Method N^o 2 can be considered more reliable because temperature of surroundings was higher after the irradiation than before that, and the values of the negative derivatives are lower a little than it would be if temperature of surroundings is kept constant. Finally, the results in Tables 1 and 2 are those restored by N^o 2 method. Examples of positive derivatives behavior are shown in Figs. 4 and 5.

Table 1

Initial heating rates and respective dose rates

		dT/dt, K/sec	**mW/g, P=0.243 MW**	**mW/g, P=1 MW**
1	Copper ring	$(8.4 \pm 0.2)\ 10^{-3}$	3.0 ± 0.1	12.7 ± 0.5
2	Water in bowl N^0 1	$(2.9 \pm 0.2)\ 10^{-3}$	10.8 ± 0.7 *)	46 ± 3 *)
3	Water in bowl N^0 2	$(3.2 \div 3.5)\ 10^{-3}$	12.6 ± 0.6 *)	53 ± 3 *)
4	Water in bowl N^0 3	$(3.2 \div 3.5)\ 10^{-3}$	12.6 ± 0.6 *)	53 ± 3 *)

Note:*) - dose rate in water.

Table 2

Dose rates in water, mW/g/MW

		Site 1*	Site 2*	Site 3*	Site I*	Site II*	Site III*
1	Calorimetry, water in s.s. bowls, total dose rate:	46♥	53♥	53♥			
2	The same, dose rate by neutrons only:	33	40	40			
3	Calculation, based on neutron fluxes, epithermal part:	-	-	-	18	10	8
4	The same, fast neutron part:	-	-	-	27	31	22
5	Dose rate by all energy neutrons:	-	-	-	45	41	30
6	Total dose rate (neutron+gamma):	-	-	-	58	54	43
7	Total dose rate estimated from the row 6 values with account on geometry factors	39♣	51	46			

Notes: * - See sites numbering in Fig.2.

♥ - Uncertainty of the values is 6÷7%.

♣ - This value is quite approximate.

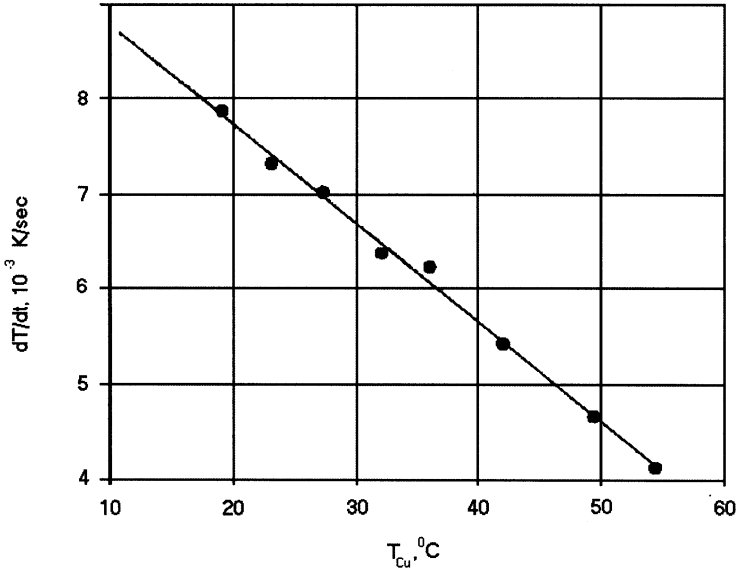

Fig. 4 Time derivative of temperature of the cupper sample versus time

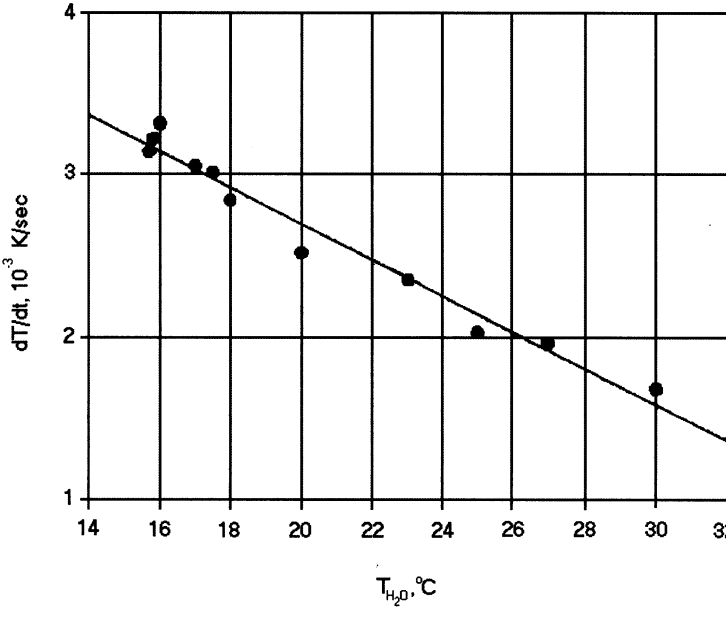

Fig. 5 Time derivative of temperature of the water sample N^{0}3 versus time

Gas pressure in a volume space of polythelene sample appeared to be linear in time as expected; in the volume of 168.9 cm^3 the gas pressure was increasing with rate of 5.8 μbar/sec during irradiation at 243 kW of reactor power. It gives 90 mW/g/MW absorbed dose with an uncertainty of about 10% (7% of which is due to the pressure meter error and the rest – due to not precise knowledge of which part of the volume is "warm" during irradiation and which is under "room temperature" condition). Gas production factor was chosen to be equal to $3.1 \cdot 10^{-7}$ mol/J. Converting a dose rate value from polyethylene to water by a formula

$$\frac{Q_{CH_2} - Q_\gamma}{Q_{H_2O} - Q_\gamma} \cong \frac{M_{H_2O}}{M_{CH_2}} \cong \frac{18}{14},$$

which assumes that neutron scattering part of dose is inverse proportional to the number of hydrogen atoms per gram, and the gamma part of dose Q_γ is insensitive to composition and equal to that of copper, we have $Q_{H_2O} = (73 \pm 7)$ mW/g/MW. This is 1.2÷1.6 times more than the value of dose rate in water retrieved from direct measurements by calorimetric method – (53 ± 3) mW/g/MW. There are two evident reasons for the discrepancy:

- The copper ring reflects more radiation (both gammas and neutrons) onto the polythelene than onto the water filled capsules. Rough estimation gives this correction to be about 10÷12%.
- The barrels with water are inside a shadow of neutron flux made by KO-1 control block whereas the polythelene container is on the flux; it makes the dose rate at the polythelene site about 15% more.

Then, the dose rate in water converted from polythelene with an account for the geometry factors and for hydrogen density, would be (55 ± 6) mW/g/MW, which is in good agreement with the directly measured value (53 ± 3) mW/g/MW.

Fast neutron spectra and evaluated neutron fluxes are given in Tables 3 and 4 and in Fig. 6. The values correspond with the earlier data [4]. Evaluated neutron fluxes were used to calculate dose rate in water due to neutron scattering. Recoil protons and recoil oxygen atoms were considered to be the only contributions to the neutron dose. The latter of them is negligibly small, about (1÷1.5) mW/g/MW. Rigorous energy dependence of the elastic scattering cross-section of hydrogen was applied. Results are in Table 2, together with those restored from calorimetric measurements at steel-walled barrels filled with water. When obtaining values in the table, gamma dose was assumed to be constant inside all experimental area. If comparing contents of rows 1 and 7, one can see reasonable agreement between them within experimental error which is about 10% for the neutron flux based method.

It is worth mentioning that our results of dose rates in water and in metals are in reasonable agreement with earlier experimental results for dose rate behind water moderator at channels 4-6 [5].

Table 3

Fast neutron spectra at three positions of activation foils (see Fig.2); fluxes are in units of 10^9 n/cm^2/sec/MeV, energy in MeV, for 1.5 MW reactor power.

E	Site I	Site II	Site III
0.2	2760.0	3251.0	2320.0
0.4	1455.0	1712.0	1228.0
0.6	1005.0	1187.0	841.0
0.8	777.5	910.2	646.1
1.0	637.4	744.4	525.2
1.2	522.5	608.5	426.6
1.4	428.2	497.3	346.2
1.6	350.8	406.3	280.8
1.8	287.5	331.8	227.6
2.0	235.5	271.0	184.4
2.2	193.0	221.3	149.3
2.4	158.3	180.8	120.8
2.6	129.8	147.7	97.8
2.8	106.5	120.7	79.1
3.0	87.5	98.7	64.0
3.2	71.9	80.8	51.8
3.4	59.2	66.2	42.0
3.6	48.7	54.3	34.0
3.8	40.2	44.6	27.6
4.0	33.3	36.7	22.5
4.2	27.6	30.3	18.3
4.4	22.9	25.0	15.0
4.6	19.1	20.8	12.3
4.8	15.9	17.3	10.1
5.0	13.3	14.4	8.3
5.2	11.2	12.1	6.9
5.4	9.5	10.1	5.8
5.6	8.0	8.6	4.9
5.8	6.8	7.3	4.1
6.0	5.8	6.2	3.5

Table 4

Fast (integral), thermal and epithermal neutron fluxes at three positions of activation foils (see Fig.2) for 1.5 MW reactor power.

	Fast neutrons E>0.4 MeV, 10^{12} n/cm^2/sec	**Thermal neutrons 10^{12} n/cm^2/sec**	**Epithermal neutr. 10^{12} n/cm^2/sec/eV**
Site I	1.35	1.75	0.33
Site II	1.57	1.28	0.22
Site III	1.10	0.97	0.18
Site IV	0.66	-	-

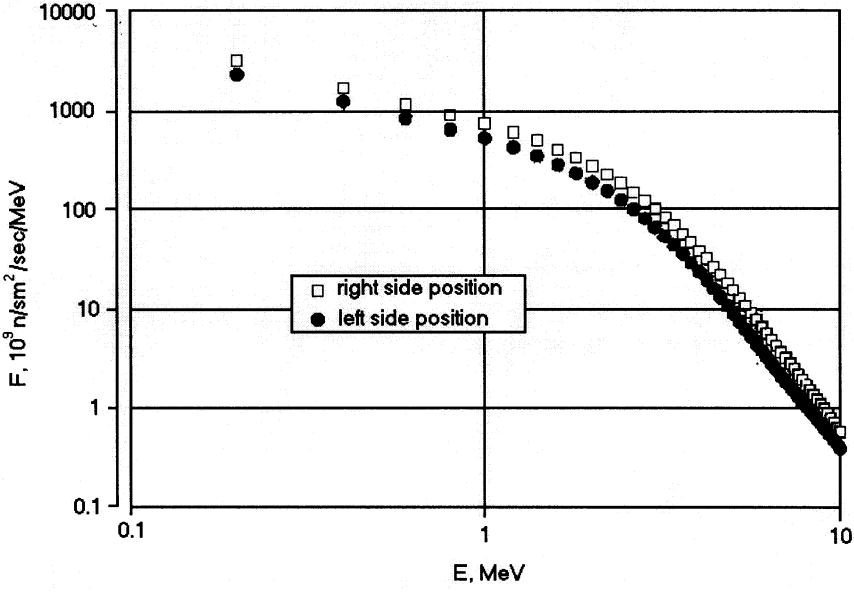

Fig. 6 Fast neutron spectra at the two positions of the activation foils, See Fig. 2. Neutron flux at the central position is in between them.

In the Table 5 dose rates at the site of the polythelene capsule are shown. This site is most important because it corresponds to the site of an irradiation chamber of URAM-2 project. As it was already mentioned, there was a significant difference between the dose rate extracted from radiolytic gas measurement and that of other two methods. But after corrections which were made to take into account the geometry factors mentioned above, all values were brought into good agreement, see rows 3÷5. The averaged value (65 ± 5) mW/g/MW would be as good as to be a conventional value for the dose rate in water at the site of the polythelene. It occurs to be within the error ranges for both calorimetric and radiolytic gas production methods of dose rate measurement, and the neutron flux based calculations. In line with this, an absorbed dose rate in solid methane should be 0.12÷0.14 W/g/MW.

Table 5

Dose rates in the supposed center of the URAM-2 irradiation chamber

	Sample, method of acquisition	**Dose rates, mW/g/MW**
1	Polythelene, experiment, gas production method	90 ± 9
2	The same, corrected for the copper ring effect	80 ± 9
3	Water, converted from the row 2 value by Eq.(1)	64 ± 8
4	Water, experimental values corrected for the KO-1 and copper ring effects (corrections for the real position of the chamber)	68 ± 4
5	Water, retrieved from neutron fluxes values and corrected for the real position of the chamber	63 ± 3
6	Water, the conventional value	65 ± 5
7	Methane, converted from the row 6	130 ± 10

Acknowledgements.

The authors are eager to express their great respect to V. Lushchikov and E. Strelkova who have assisted in instrumentation and processing of the data.

References:

1. V.V. Golikov, G.Ya. Kaskanov, E.N. Kulagin et al. Large-Scale Samples Irradiation Facility at the IBR-2 Reactor. JINR Communication, P13-96-403, 1996 (in Russian).
2. E.P. Shabalin, H. Ullmaier, G.S. Bauer, A.V. Androsov, V.V. Golikov, L.B. Golovanov, V.I. Konstantinov, E.N. Kulagin. URAM-2: Irradiation Experiments at the Dubna IBR-2 Reactor (Scientific Grounds and Detailed Programme). ESS Report 99-92-T, Forschungszentrum Juelich, 1999.
3. K.G. McLaren. Int. J. Radiation&Isotopes, V.25, p.87, 1974.
4. V.V. Golikov, E.N. Kulagin, V.I. Lushchikov, E.P. Shabalin. The Facility for Commercial Doping of Silicon by Thermal Neutrons in Channel 3 at the IBR-2. JINR-Communications, Dubna, 18-94-108, 1994 (in Russian).
5. V.V. Melikhov, E.P. Shabalin. Measurement of Heat Release in Hydrogenous Moderator. JINR Communications, P3-86-592, 1986. (in Russian).

Received on April 25, 2002.

Голиков В. В., Кулагин Е. Н., Шабалин Е. П. E16-2002-79

Мощности доз около водяного замедлителя реактора ИБР-2: эксперимент и анализ

Данная работа посвящена измерению мощности поглощенной дозы в металлах и водородосодержащих материалах (полиэтилен, вода) на канале № 3 реактора ИБР-2 в непосредственной близости от водяного замедлителя нейтронов [1]. Были использованы три метода определения доз, которые дали сравнимые результаты. Для меди мощность дозы составила 0,013 Вт/г на 1 МВт мощности реактора с точностью ±3 %, для полиэтилена (0,090 ± 0,009) Вт/г/МВт и для воды (0,053 ± 0,003) Вт/г/МВт.

Работа выполнена в Лаборатории нейтронной физики им. И. М. Франка ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2002

Golikov V. V., Kulagin E. N., Shabalin E. P. E16-2002-79

Dose Rates Near Water Moderator of the IBR-2 Reactor: Experiment and Analysis

Adsorbed dose rates in metals and in hydrogenous materials (polyethylene and water) have been measured at the neutron beam channel No. 3 of the IBR-2 reactor just behind the light water moderator [1]. Three methods have been applied; all of them gave the comparable results, if accounting for some corrections due to nonuniformity of the irradiation field. In metals (copper) it appeared to be 0.013 W/g/MW of the reactor power with an accuracy to ±3 %; in polyethylene and water — (0.090 ± 0.009) and (0.053 ± 0.003) W/g/MW, respectively.

The investigation has been performed at the Frank Laboratory of Neutron Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 2002

Макет *Т. Е. Попеко*

ЛР № 020579 от 23.06.97.
Подписано в печать 30.05.2002.
Формат 60 × 90/16. Бумага офсетная. Печать офсетная.
Усл. печ. л. 1,0. Уч.-изд. л. 1,04. Тираж 240 экз. Заказ № 53310.

Издательский отдел Объединенного института ядерных исследований
141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.