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Different methods of correcting the readings of the DVGN-01 albedo neutron dosimeter placed behind the IBR-2M protection

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The paper presents the results of correction of readings of DVBN-01 albedo dosimeters behind IBR-2M protection, the Neutron Physics Laboratory of the Joint Institute for Nuclear Research (JINR), Dubna, by various methods. The neutron spectra were measured at two points behind the IBR-2M protection in the experimental halls, and measurements were carried out with the spherical albedo system at these points. The correction coefficients for DVGN-01 were calculated from the measured spectra based on the data of the spherical albedo system. A good agreement of the coefficients calculated by different methods is shown, which indicates the reliability of the obtained values for the correction coefficients. Based on the results of this work and the data obtained in the other investigations, the values of correction factors recommended for use in individual radiation control (IRC) in the FLNP were obtained.

Keywords: albedo neutrons, IBR-2M reactor, DVGN-01 readings.

Introduction

In accordance with the "Radiation Safety Standards 1999/2009," when personnel work in the fields of ionizing radiation, it is necessary to carry out radiation control [1]. The radiation control is subdivided into individual radiation control

(IRC) and workplace radiation control. The IRC is carried out to determine the degree of radiation risk in occupational exposure, the possibilities of reducing it and preventing the personnel from overexposure. It is carried out by individual dosimeters worn on the body of the personnel (as a rule, in the breast pocket of working clothes). Using the data, the radiation doses in mSv obtained by an individual worker are determined.

One of the main characteristics of neutron radiation dosimeters is their energy dependence of response (EDR). EDR of an ideal individual neutron dosimeter must be similar to the energy dependence of an individual dose equivalent at a depth of 10 mm per unit neutron fluence. This value is often called the specific individual dose equivalent and is denoted as $h_p(10)$.

Figure 1 shows the energy dependence of a specific individual equivalent on the neutron dose for a phantom in the form of a flat tissue-equivalent plate with dimension of $(30 \times 30 \times 15)$ cm, imitating a human body with a perpendicular neutron incidence on its surface.

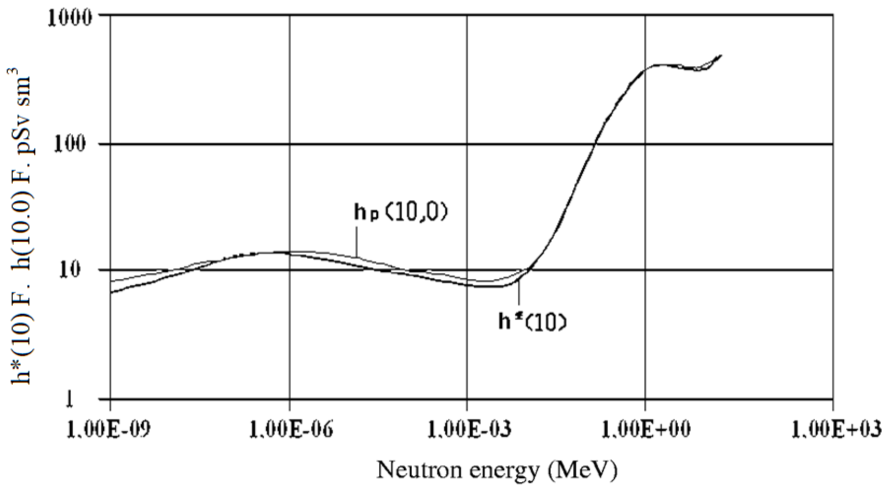

Figure 1. The energy dependence of specific individual (hp(10)) and ambient dose (h*(10)) equivalents.

At present, one of the most common methods of individual dosimetry of neutron radiation is the albedo method. It is based on the registration of thermal neutrons reflected and coming out from the human body by a dosimeter located on the body surface. On the basis of albedo dosimeters, several foreign and domestic systems were created, the main elements of which are individual dosimeters and their data readers. One of them is the AKIDK-301 and AKIDK-302 systems with the DVGN-01 dosimeters, produced by the Angarsk instrument plant [2]. The dosimeter cassette has two thermoluminescent detectors ^6LiF and $^7LiF \oslash 5x0.9$ mm in size under a 0.65 cm thick polyethylene moderator, covered with a boron filter and a 30 μm thick foil to align the energy dependence of dosimeter to photons. Figure 2 shows the EDR of the albedo neutron monitor DVGN-01 for various irradiation geometries, isotropic (ISO) and anteroposterior (AP), and different phantom types [3].

A comparison of figures 1 and 2 shows that EDR of dosimeter DVGN-01 differs significantly from the required dependence. As a result, there is a difference between the dosimeter readings and the true values of the neutron dose and

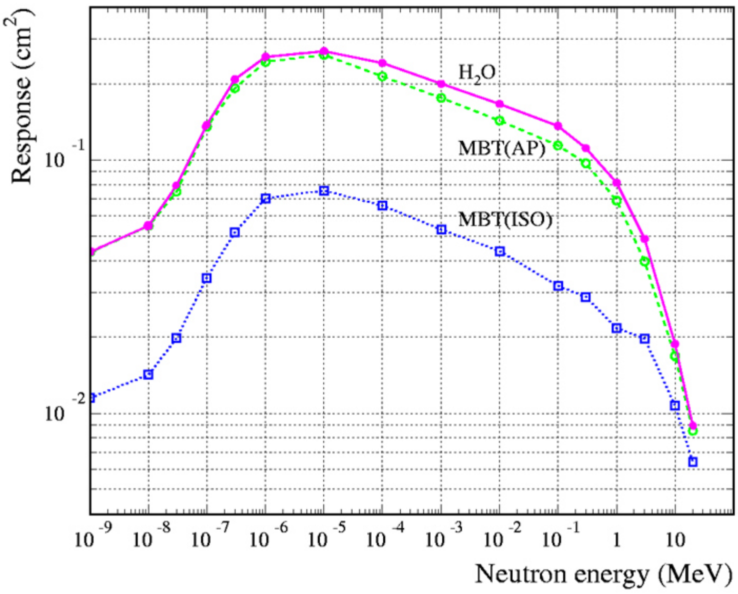

Figure 2. EDR of the albedo dosimeter DVGN-01: H_2O – water phantom in the form of a parallelepiped with dimensions of (30x30x15) cm with plexiglass sides; MBT(AP), MBT(ISO) – tissue equivalent (MBT – soft biological tissue) elliptic cylinder with dimensions of (20 × 40 × 60) cm.

it is necessary to introduce a correction into the DVGN-01 readings using the correction factors. There are two main methods for correcting the indications of albedo dosimeters: the computational method [3, 4] using known neutron spectra and the EDR dosimeter and the experimental method using a spherical albedo system [5, 6]. In this work, both of these methods were used by measurements of neutron spectra and measurements with ball albedo system. The system consists of a polyethylene ball 25.4 cm in diameter on the surface of which six DVGN-01 dosimeters are located symmetrically relative to the center. Conventionally, these positions can be defined as up, down, right, left, back and forth with respect to the predominant direction of the neutron radiation incident on the ball. The correction factors obtained by these methods were compared.

Measurements in the experimental halls 1 and 2 of the IBR-2M reactor

Measurements were carried out in two experimental halls of the IBR-2M reactor: at point 1 in hall 2 and at point 2 in hall No. 1. Figure 3 shows the plan of the experimental halls and measurement points. Figure 4 shows as an example the photograph of the measurement site at point 1.

At points 1 and 2, neutron spectra were measured using a portable multi-ball spectrometer. The detector of thermal neutrons of the spectrometer is a LiI (Eu) scintillator of (4.3 × 4) mm in size, enriched with ^{6}Li up to 90%. A set of polyethylene spheres with diameters of 2, 3, 5, 8, 10, 12 inches was used as moderators, and measurements were made with a detector without a moderator and with a detector in a cadmium case. The neutron field was monitored using a ^{3}He counter in a cylindrical polyethylene moderator. Spectrum reconstruction, i.e.

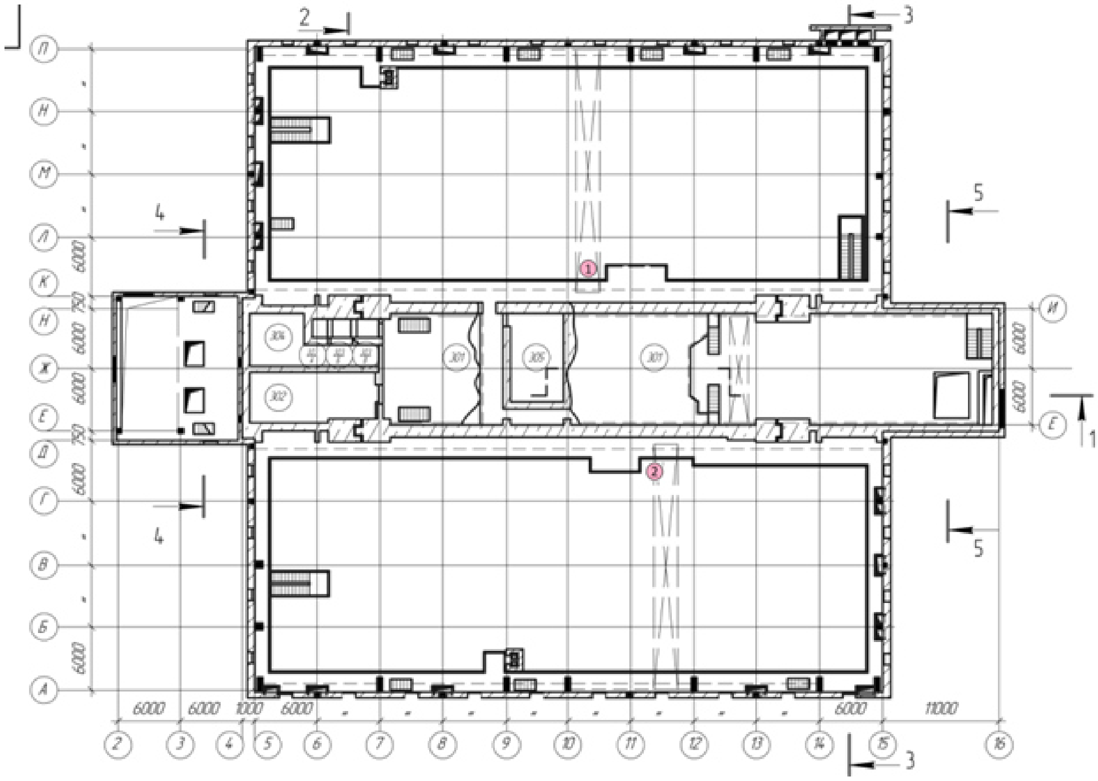

Figure 3. Plan of the IBR-2M experimental halls and measurement points.

Figure 4. Place of measurements at point 1 of experimental hall No. 2.

solution of the inverse problem, is based on the method of statistical regularization. The program uses an algorithm for the numerical solution of a system of algebraized equations.

$$N_i = \int_{E_{min}}^{E_{max}} F(E)R_i(E)dE, \quad i = 1, ..., m \tag{1}$$

Here E_{max}, E_{min} are the boundaries of the neutron energy spectrum $F(E)$, $R_i(E)$ of the response function of the spectrometer with a moderator of the i th diameter (imp-cm^2 neutron^{-1} MeV), N_i -spectrometer readings (count rate, imp^{-1}). When reconstructing the spectra, apriori information, as a requirement for the smoothness of the guess spectrum $F(E)$ and a limitation of the spectrum from above with an energy of 20 MeV was used.

Results and discussion

Figure 5 shows reconstructed neutron spectra in points 1 (channel No. 3) and 2 (channel No. 11). These neutron spectra have a characteristic appearance due to the weakening in the protection of channels of the spectrum of fission neutrons with a maximum energy of up to 10-15 MeV and multiple leakage neutron scattering in the experimental room of the reactor (accumulation of thermal neutrons).

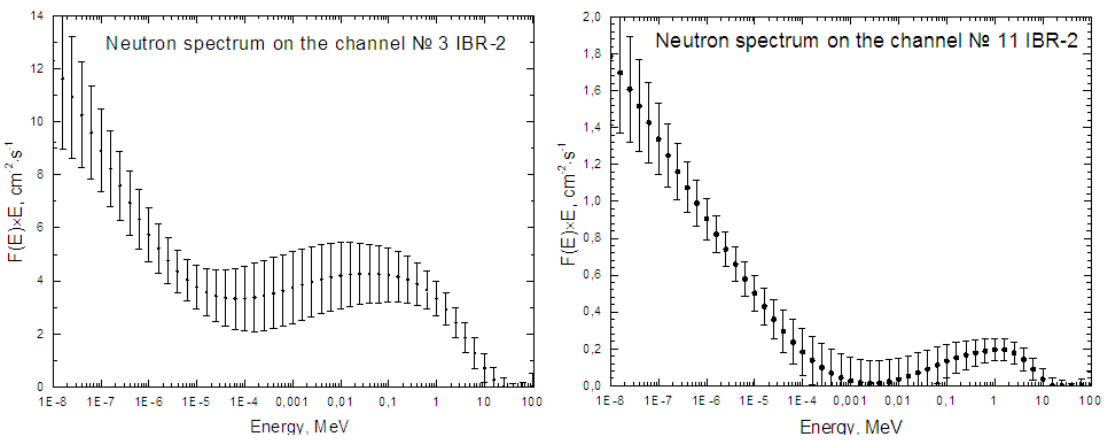

Figure 5. Spectra of neutrons at points 1 and 2. The average energy of the spectrum at point 1 is 218 keV, at point 2 it is 129 keV.

At points 1 and 2, measurements were also carried out with a spherical albedo system. The results of measurements with the spherical albedo system and calculation of the values of the correction coefficients for the measured neutron spectra are presented in Table 1.

It shows the averaged values of the DVGN-01 readings on the surface of the ball H_s, the readings of the dosimeter slide in the center of the ball H_c, the ratios of these readings H_c/H_s, the results of calculations of correction factors for the spherical albedo system for the K_E (ISO) isotropic geometry and for the individual dose equivalent K_H (AP) in the anteroposterior geometry and the results of calculation of these coefficients based on the measured neutron spectrum.

Table 1.
Results of measurements with a spherical albedo system and calculations by the spectrum.

Place of measurements	Point 1	Point 2
Average spectrum energy, keV	218	129
H_s,mSv	38.7	2.4
H_c,mSv	17.9	0.8
H_c/H_s	0.46	0.34
K_E(ISO) Calculation by formula	0.111	0.076
K_E(ISO) Calculation by spectrum	0.082	0.055
K_E(ISO) Average	0.097	0.065
K_H(AP) Calculation by spectrum	0.064	0.040
K_H(AP) Calculation by formula	0.087	0.062
K_H(AP) Average	0.075	0.051

The dependence of the correction factors on the H_c/H_s ratios for low-energy spectra of JINR is approximated by the following formulas:

$$K_E(ISO) = 0.297 \cdot (H_c/H_s)^{1.264}$$
$$K_H(AP) = 0.221 \cdot (H_c/H_s)^{1.071}, \quad (2)$$

The coefficients contained in the formula are determined experimentally depending on the ratio H_c/H_s for various sources of neutrons. The table also gives the average values of the coefficient at each point, calculated by these two methods.

Analysis of the results and comparison with literature data

Table 2 presents the results of comparison of the values of the correction coefficients obtained in this work with the correction coefficients from the literature data obtained earlier at the JINR pulsed reactor IBR-30, as well as in the low-energy spectra at the other JINR facilities: IREN, U-300 microtron and MT-400 FLNR, where the average energy does not exceed several hundred keV.

Table 2.
Comparison of the results with literature data.

No.	Facility	Average spectrum energy, keV	Average specific ambient equivalent dose of neutron spectrum [8], pSv·cm^2	$K_n(AP)$	$K_E(ISO)$
1	Phasotron	258	30.5	0.045	0.057
2	IBR 30	93	37.4	0.038	0.048
3	IBR 30	210	54.8	0.062	0.082
4	IBR 30	242	60.8	0.065	0.088
5	IBR-2M p.1	218	55.8	0.075	0.097
6	IBR-2M p.2	129	34.0	0.051	0.065
7	U-300	267	60.2	0.065	0.104
8	U-300	245	95.7	0.111	0.128
9	U-300	588	39.0	0.040	0.046
10	IREN	257	43.6	0.093	0.105
11	MT-400	230	53.6	0.060	0.080

The results presented in Tables 1 and 2 enable us to make the following conclusions:

• The neutron spectrum at points 1 and 2 is a low-energy spectrum with an average energy less than 1 MeV and an H_c/H_s ratio less than 1, which indicates the validity of using the spherical albedo system for such neutron spectra.

• The values of the correction coefficients determined by various methods - by calculation using the spectrum and a spherical albedo system, differ from the mean values by no more than 20%, which indicates a good agreement between the two methods and reliability of the obtained coefficients.

• The obtained results indicate the possibility of using the spherical albedo system for correcting the indications of albedo dosimeters behind the protection of the IBR-2M reactor and in the low-energy spectra of such facilities as LNR accelerators.

• The results of comparison of the obtained correction factors with the literature data for low-energy spectra show good agreement. However, they correlate better not with the average energy of the spectrum, but with the ambient equivalent dose per unit fluence (specific dose) for a given spectrum.

• The values of the correction factors for both coefficients, as a rule, do not exceed the values of 0.10, except the spectrum on the U-300 with a specific dose value close to 100 pSv cm^2. These results are in good agreement with the data [7] for low-energy spectra behind the protection of MTs-400 FLNR, where the correction coefficients generally do not exceed the values of 0.10.

• It should be noted that the values of the correction factors K_H (AP) and K_E (ISO) for measurement points at IBR-2 are very close. This suggests the correctness of the determination of the normalized effective dose by finding the recommended operating value of an individual dose equivalent in the anteroposterior geometry based on the results of radiation control.

Conclusion

As a result of this work, neutron spectra were measured and measurements were made in low-energy spectra using a spherical albedo system at two points behind the protection of the IBR-2M reactor in the experimental hall.

The values of the correction factors were determined for the indications of the individual albedo dosimeter DVGN-01 at these points by two methods: by calculations using the measured spectra and using a spherical albedo system.

A good agreement between the values of the correction factors determined by these methods were obtained, which indicates the validity of using the spherical albedo system to find the values of the correction factors behind the IBR-2M protection.

Close values of the correction factors for the ambient dose equivalent K_H (AP) and the effective dose K_E (ISO) indicate the correctness of the determination of the normalized effective dose by finding it according to the results of the recommended operating value - the individual dose equivalent.

It is recommended to use in the individual radiation control in FLNP the value of the correction factor for the DVGN-01 readings, equal to 0.10.

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