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ACTIVATION METHOD FOR MEASUREMENT OF NEUTRON SPECTRUM PARAMETERS

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ABSTRACT

Experimental researches of spectrum parameters of neutrons at nuclear installations RRC KI are submitted The installations have different designs of the cores, reflector, parameters and types of fuel elements. Measurements were carried out with use of the technique developed in RRC KI for irradiation resonance detectors UKD. The arrangement of detectors in the cores ensured possibility of measurement of neutron spectra with distinguished values of parameters. The spectrum parameters which are introduced by parametrical representation of a neutrons spectrum in the form corresponding to formalism Westcott.

On experimental data were determinate absolute values of density neutron flux (DNF) in thermal and epithermal area of a spectrum (F_t, f_{cpi}), empirical dependence of temperature of neutron gas (Tn) on parameter of a rigidity of a spectrum (z), DNF in transitional energy area of the spectrum. Dependences of spectral indexes of nuclides (UDy/UX), included in UKD, from a rigidity z and-or temperatures of neutron gas Tn are obtained.

Tools of mathematical processing of results are used for activation data and estimation of parameters of a spectrum (F_t, f_{cpi}, z, Tn, UDy/UX).

In the paper are presented some results of researches of neutron spectrum parameters of the nuclear installations [1-8].

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ABSTRACT

The method activation researches parameters of neutron energy spectral are developed in RRC KI. The method use multi component detectors, which were named “Unified Composite Detectors” (UKD). Methodical basis of the measurements is Westcott formalism for representation of a spectrum in thermal and epithermal areas of energies [1, 2]. Parameters of the spectrum are: F_t - thermal flux, f_{epi} - parameter epithermal flux and Tn - temperature of neutron gas. The detector includes nuclides - targets ^{164}Dy, ^{55}Mn, ^{197}Au, ^{186}W, ^{81}Br. They are used for determination of absolute values of DNF of thermal (F_t) and parameter (f_{epi}) epithermal neutrons: nuclides ^{164}Dy, ^{55}Mn - for thermal area and nuclides ^{197}Au, ^{186}W, ^{81}Br - for epithermal areas - (up to 120 eV). Detectors with nuclide ^{115}In are used for estimations of DNF in transitional area of the spectrum.

The method was applied at definition of parameters of spectra in various nuclear research installations RRC KI “ Kurchatov institute ” (reactor Ф-1, zero power critical facilities - prototypes of reactors VVER, RBMK, HTGR) [1 - 8].

1. MEASUREMENT TECHNIQUE AND DATA PROCESSING

The measurement technique and data processing is based on [1 - 8]:

- assumption about a possibility of parametrical representation of a researched part of a spectrum in the form corresponding to Westcott formalism;
- researches on nuclide composition for the activation analysis on the basis of which detectors UKD have been made;
- recommendations under the order of the arrangement and irradiation UKD on nuclear installations;
- using of the γ - analyzer on the basis of super pure germanium crystal for counting activity UKD
- processing and calculations data on activity of nuclides in UKD.

According to theoretical recommendations, and also proceeding from the analysis of the our experimental and calculated data [1 - 8], the spectrum of neutrons in low-energy area, according to Westcott formalism, is represented as:

$$\Phi(E) = \begin{cases} F\,E\cdot\exp(-E / E_0), & \text{if } 0 < E \le E_M(z); \\ \Delta(E, Tn, z) / E, & \text{if } E_M(z) < E \le E_\Phi(z); \\ f_{epi} / E, & \text{if } E_\Phi(z) < E < \max E_\Phi \end{cases} \qquad (1)$$

where $E_0 = k\cdot Tn$;
k – Bolzman’s constant;
F – flax of thermal area of a spectrum (Maxwell spectrum);
f_{epi} – parameter epithermal spectrum ($fepi = {}_{E}\int^{eE} F_{epi}(E)\, dE$)
$E_M(z)$ – boundary of thermal part of spectrum and the lower boundary of transitional area of spectrum ($0,15\ eV \le E_M(z) < 0,25\ eV$);
$\Delta(E, Tn, z) / E$ – function of transitional area of a spectrum;

$E_Ф(z)$ – boundary of transitional area and the part of a spectrum circumscribed by a spectrum of Fermi (0,25 eV $\leq E_Ф(z) <$1,0 eV).

The unified composite detectors are optimal for researches on nuclear installations RRC KI include five nuclides ^{164}Dy, ^{55}Mn, ^{197}Au, ^{186}W and ^{81}Br. The example of nuclide composition UKDt (UKD in titanic capsule) is presented in table 1.

Table 1 Nuclide composition UKDt,

Number UKDт	Nuclide masses [mg]				
	^{164}Dy	^{55}Mn	^{197}Au	^{186}W	^{81}Br
1	3,005	1,467	2,493	29,75	47,50
2	3,616	1,291	2,322	17,66	43,84
3	3,151	1,531	2,667	21,24	52,54
4	2,924	1,443	2,418	19,60	47,66
5	3,045	1,524	2,547	20,07	48,12
6	3,302	1,582	2,654	22,48	51,40
7	3,253	1,567	2,667	21,75	53,47
8	3,063	1,459	2,488	19,35	51,80
9	2,622	1,316	2,575	20,96	49,71
10	3,050	1,469	2,548	20,10	53,33
Δ_{*p}	3,5	3,5	3,0	3,0	4,0

Δ_{*p} – error of weight, %.

Values of some nuclear - physical parameters of the nuclides are presented in table 2.

Table 2 Nuclear physical parameters of the nuclides

Nuclide	$T_{1/2}$	λ	n	σ_{act}	I_{Cd}
^{165}Dy	2,300	0,30137	1,0415×1018	2520	341
^{56}Mn	2,575	0,26918	10,969×1018	13,3	14
^{198}Au	66,68	0,010395	3,0578×1018	98,65	1550
^{186}W	24,04	0,028833	0,9370×1018	37,0	485
^{82}Br	35,3	0,019636	3,7160×1018	2,70	50
^{115}In	0,90		5,3×1018	162	2650

In the table: $T_{1/2}$ - *a half-life of an nuclide, hour*;
λ - a constant of disintegration j-th an nuclide, hour $^{-1}$;
n - number of atoms j - th an nuclide in 1 mg material;
σ_{act} – cross-section of activation, barn;
I_{Cd} – resonant integral, barn.

The UKDт design allows placing detectors in research nuclear installations. The nuclide masses were calculated for application at fluency neutrons up to 10^{11}n/sm^2 and calibrated at reactor Ф-1.

There are 1 – 3 hours passes after finishing of irradiation on nuclear installation (15 – 30 minutes) and transportation of the irradiated detectors for measurement of γ - spectrum at the γ - analyzer ORTEG. Duration of the measurement of one sample at γ - spectrometer makes 10 – 20 minutes. Samples are placed on distance of 10 - 30 cm from the detector depending on the directed activity. An absolute value of effectiveness of sensitivity of γ-quantum are checked with the help of exemplary certificated source (OSGI). The effectiveness of sensitivity γ - quantum ($\varepsilon I\gamma$) on intensity, energy and distance from samples up to the detector is determined by measurements of the big number specially made γ- sources (^{110}Ag, ^{152}Eu, etc.). For one cycle irradiation - measurement in conditions RRC KI can be processed to 20 samples.

Processing of activation data UKDт carried out by using of code ASTRA. At the processing are used input data:
- the tabulated data on nuclear - physical performances of nuclides;
- values of weights of the elements, component each UKD;
- estimated amount of counting of γ - peaks for each the nuclide;
- effectiveness of recording of γ - peaks;
- values of duration of an irradiation, the subsequent waiting up to counting and counting;
- the a priori value Tn obtained on operating experience of nuclear installation.

For each nuclide are calculated velocities of activation reactions Uj. In the method Uj is represented by the sum of velocities of the reactions in thermal and epithermal areas

$$Uj = U_{j,T}+U_{j,epi} = F_t\, \sigma(Tn)_{eff,j} + f_{epi}\, I_{Cd,j}. \qquad (2)$$

where j = 1, 2, 3, 4, 5 correspond ^{164}Dy, ^{55}Mn, ^{197}Au, ^{186}W, ^{81}Br;
$U_{j,T}$ and $U_{j,epi}$ – activation in thermal and epithermal areas of a neutron spectrum for j-th nuclide;
$\sigma(Tn)_{eff,j}$ - the effective cross-section of thermal neutrons averaged on distribution of Maxwell with temperature of neutron gas T_n;
$I_{Cd,j}$ - cadmium resonant integral.

The ASTRA code solves the over determined system of five equations (2) by method of least squares. Solutions of set equations (2) are F_t and f_{epi}.

The parameter of a rigidity $z = F_t / f_{epi}$ is calculated on F_t and f_{epi}.

The dependence between parameter z and temperature of neutron gas was fined according to experimental researches and calculations of modeling. It is

$$Tn(z) = a / z + b. \qquad (3)$$

According to experiment data a = 1850, b = 278,5.

For estimation of measured temperature of neutron gas have used the iterative procedure. In beginning of each iteration is used the value temperature T_n. (in the first iteration is used a priori value T_n) for calculation $\sigma(Tn)_{eff,j}$. Value T_n found on the previous iteration, is used in the following iteration for updating $\sigma(Tn)_{eff,j}$ and calculation new F_t, f_{epi}, z and value Tn. Iterations well converge and values of last iteration, point (T, z), with big exactitude lie down on the curve (3) (Fig. 1).

There is dependence of spectral indexes (Udy/Ux_j $j \neq 1$) of UKD nuclides from rigidity z and-or Tn are obtained.

The essential moments providing results of the measurements are:
- possibility of neutron calibration for UKD on weight;
- using of the certificated equipment and a technique of measurement of sample activity;
- using empirical dependence of neutron gas temperature from parameter of rigidity (3);
- application of program MCU [9, 10] for modeling spectra;
- presence of the software on a γ – the analyzer and for counting activation of UKD estimation of spectrum parameters.

The technique is approved at various nuclear installations RRC KI [1 - 3, 6, 8].

2. NOTE ON MEASUREMENTS AT NUCLEAR INSTALLATIONS RRC KI

Reactor Ф-1 [1, 6 - 8]. On December, 25, 2006 was fulfillment 60 years from the date of start-up the first on continent of Eurasia of nuclear reactor **Ф-1**. At the reactor are certificated three cavities for irradiations:
- the horizontal channel which is pass through the central plane of a reactor;
- the channel of a graphite thermal column;
- the vertical channel in diameter for graduation measurements.

These cavities were used for test measurements and neutron calibration of UKD on weight.

Zero power critical facilities with fuel elements VVER type [2, 3, 5, 7, 8]. Measurements of spectrum parameters on fuel elements, in fuel elementax and between fuel elements were repeatedly carried out at critical facilities "П" and "Скфиз". The most interesting are measurements on study of effectiveness of moderator density decrease. The core of critical facility "П" was inhomogeneous on cross-sectional and height. The inhomogeneous was formed by the short aluminum tubes which in the core center were put on the lower half of fuel elements. Ten detectors UKDt and samples with ^{115}In were placed in empty clads of fuel element. The clads have two detectors and were placed in the core in region of the arrangement fuel elements and in reflector. Measurements at critical facility "П" are carried out in the big range of the rigidity ($3 < z < 75$; $300 < Tn < 722$). It is possible to note:
- spatial dependence of rigidity;
- softening of the spectra in direction from the center to reflector;
- there is substantial increase F_t and a significant decrease f_{epi} in a fuel lattice in a direction from center to rim;
- on height of DNF differed from 2 up to 5 times, and z and Tn – up to 1,5 times;
- significant decrease of a DNF of epithermal neutrons in a reflector.

General estimation of results of measurement – heterogeneity of the spectrum parameters on radius and azimuth of the core and in reflector.

Critical facility with fuel elements HTGR type [3, 5, 7, 8]. Critical assembly of the facility has the following features:
- spherical fuel elements, made in graphite basis, are loaded in the ring core;
- two reflectors – central and peripheral.

Detectors were placed in vertical tubes in reflectors and the core.

Under the analysis of results of measurements is marked the significant heterogeneity of a rigidity on radius of the core and reflectors.

Critical facility RBMK type. Critical assembly of the facility imitating the core of reactor RBMK is formed from graphite blocks with channels for fuel assemblies. Detectors were placed in channels and between graphite blocks.

Under the analysis of results of measurements is marked significant the decrease of a rigidity between blocks.

3. RESULTS OF EXPERIMENTS

Ft, fepi, z and Tn for various nuclear installations. The summary review of the measured parameters for various nuclear installations presented in Table 3.

Table 3. Measured limiting parameters for various nuclear installations

Parameters			Φ-1	VVER	HTGR	RBMK
Ft	Max	The core	5.128e+9	3.78e+8	1.94e+8	3.150e+7
	min		1.213e+9	1.17e+7	1.2e+8	1.520e+7
Ft	Max	Reflector	1.31e+7	4.09e+6	2.94+8	6.081e+6
	min		<1.0e+4	3.0e+5	2.29e+7	
fepi	Max	The core	2.410e+9	4.26e+7	1.18+7	9.891e+5
	min		5.11e+7	3.31e+6	4.50e6	8.236e+5
fepi	Max	Reflector	<1.0e+4	7.36e+3	8.0e+6	1.458+5
	min		<1.0e+4	1.52e+3	<1.0e+5	
Z	Max	The core	23.7	8.12	13.2	38.29
	min		21.3	4.21		15.36
Z	Max	Reflector	>400	556.2	63.4	41.71
	min		118.5	61.66	41.9	
Tn	Max	The core	379	713.9	420.0	399.7
	min		363	505.2		327.2
Tn	Max	Reflector	293	343.9	323.0	323.2
	min		284	281.9	308.4	

Limiting values of the parameters submitted in this table are obtained in various points of the cores and at different experiments.

Measurement f_{epi} in reflectors. By results of measurements for reflectors of critical facilities and the thermal column of reactor Φ-1 are observed: F_t is calculated with a good accuracy, it is impossible to tell with confidence about calculations f_{cpi} which, occasionally, accepts negative values. It, apparently, is connected with features of experimental data on activation of nuclides UKDт and insignificant of the DNF epithermal neutrons. The basic recipes of an improvement of values f_{cpi} – use more informative nuclides for epithermal areas of energy spectra and-or increase the time of irradiation .

Spectral indexes. The spectral indexes are rations of velocities of nuclear reactions of Dy to other nuclides. The values of four spectral indexes are presented as curves $U_{Dy}/U_{Mn}(z)$, $U_{Dy}/U_{Au}(z)$, $U_{Dy}/U_{W}(z)$ and $U_{Dy}/U_{Br}(z)$ on fig. 3. On the data measurements and calculations *curves of all spectral indexes are identical.* For different pairs the curves of spectral indexes differ only a constant multiplier.

The interest is represented with spectral indexes U_{Dy}/U_{Au} and U_{Dy}/U_{Br}:

U_{Dy}/U_{Au} - measurements demand a high exactitude because of a small range in area of *real values z*

U_{Dy}/U_{Br} - measurements not demands a high exactitude because of large range of values U_{Dy}/U_{Br} at real values z. For these pairs the corresponding data in table 4 are presented.

Table 4. Dependences of spectral indexes $U_{Dy}/U_{Au}(z)$ *and* $U_{Dy}/U_{Br}(z)$
for z and Tn (average according to three measurements on critical facility "П")

z	Tn	UDy/Au	UDy/Br
6,66	556	1,91	56,74
4,23	715	1,21	36,93
7,67	520	2,31	76,16
5,48	616	1,60	43,67
8,14	506	2,33	73,39
5,24	631	1,52	47,23
73,82	303	6,99	281,53
60,16	309	7,66	313,57

Errors of measurements. Errors of the method of measurement spectra parameters are determined by errors: nuclear - physical constants, positions of detectors in the cores, calculation of DNF, duration time of an irradiation, cool and measurement on a γ - spectrometer, counting for peaks γ - spectra, effectiveness of the account of activity of detectors, weights of the detector components, degree of adequacy curve Tn(z) to measured fuel composition and other.

The ASTRA code for solution of the system (2) and iteration procedure are provided for $z > 3$ error of value Tn up to $\pm 0{,}5^\circ$ if not take into account errors: determination F_t and f_{cpi}, nuclear - physical constants, values of squares of peaks a γ - spectra, effectiveness of account gamma by the analyzer, duration of three stages of time of measurement, means measurements and accuracy of calculations.

Really values of the statistical error on determination for spectra parameters are:
F_t from 3 up to 20 %, f_{cpi} from 4 up to 20 %, z from 3 up to 20 % and Tn from 1 up to 9 %.

Influence of errors on counting for peaks a γ - spectra and weights of nuclides in UKDт on the parameters investigated by the method of interval estimation. Variations of weight and the counting for peaks have opposite influence on errors of parameters: at growth of one and a diminution of another parameters increase and, on the contrary, at a diminution of one and growth of another parameters decrease, as of sensitivity factors have different signs. Ranges of deviations of parameters from calculated value are:

$F_t \pm 10\%$, $f_{cpi} \pm 6\%$, $z \pm 3\%$, $Tn \pm 6\%$, $U_{Dy}/U_X \pm 3\%$.

Errors values Tn are determined by values z:
for z <3 – Tn are estimated insufficiently precisely because of proximity of curve Tn(z) to vertical asymptote when small variations z give the big differences in Tn;
for 3 <z <60 – Tn are estimated with a good accuracy;
for z> 60 – Tn are estimated insufficiently precisely because of weak sensitivity UKD and the big indeterminacies f_{cpi}.

Methodical error of model (2). The model for velocity of reactions Uj is be valid only within the framework of Westcott formalism and not exact at other areas of spectrum. It is possible to assume that not correctly discounted effects of activation in intermediate and-or fast areas of a spectrum. Within the framework of a linear regression was tested two-factorial model with a constant term. The term could play a role of "an additional source of activation». Numerous calculations of experimental data on such model have shown the following:
effects of a constant term for spectra of rigidity z > 10 can be, but their contribution to values F_t and f_{cpi} is very small - less than 1 %;
effects of a constant term for soft spectra can be on some orders is lower than values of common velocities of reactions, but its value negative is more often.

For soft spectra z > 10, when it is possible to expect influence of intermediate area Ft and z can be overstated (Tn - it is underestimated). For rigid spectra z < 5, when the fast part of the spectrum can dominate - F_t and z can appear underestimated (Tn - is overstated) and influence of intermediate area is insignificant.

4. MODELING SPECTRA UNDER PROGRAM MCU-RFFI

Representation of spectra. The spectra of neutrons and velocities of reactions of radiation cross-section of neutrons for nuclides ^{197}Au, ^{186}W, ^{81}Br, ^{55}Mn, ^{164}Dy and ^{115}In had calculated by the code MCU-RFFI (MCU-RFFI/3) [9, 10]. Modeling was carried out for various rigidity spectra.

At modeling infinite mediums with the fissing materials having two types of homogeneous were considered at temperature 300° K:

- water + ^{10}B and graphite + ^{10}B for which various concentration of the absorber allowed to receive spectra of a various rigidity;
- water + ^{235}U and graphite + ^{235}U, for which various of a rigidity was reached by a various of enrichment ^{235}U.

The uniformly distributed source of neutrons with spectrum of fissing ^{235}U are supposed in the mediums. In such mediums the stream of neutrons does not depend on spatial coordinates for all energies and there is no leakage of neutrons. The balance of neutrons is determined only by a competition between termalization and absorption of neutrons. In water medium scattering undertakes for the messenger of hydrogen in water in view of chemical connections.

Choice of energy scale. For calculation of neutron spectra and minimizations of statistical errors in the area energies of neutrons is lower 1,0 eV intervals got out as follows:
- up to energy En = 1,0 eV – 40 intervals with an equal pitch on E;
- for energies En> 1,0 eV boundaries so that Ei+1 = exp (1,0) Ei (i – is number of interval).

Definition E0 and Em, Ft and fepi. The calculation under program MCU was investigated Westcott formalism for DNF as function Φ (E), that is defined in expression (1). Calculated value of spectrum parameters F_t, f_{epi}, z and values of temperature of neutron gas Tn has been obtained.

For definition E0 was considered function ln(Φ(E) / E) at thermal area for which the spectrum described by spectrum of Maxwell corresponds to a sloping straight line. On its trend were determined E0 and energy Em. After E>Em ln(Φ(E) / E) starts to deviate from linear. Values Em vary from 0,15 eV for z = 69.9, up to 0,25 eV for z = 0.69. In figure 2 graphs of energy spectra neutrons for graphite are presented.

Temperatures of neutron gas (Tn). It was determined on value E0 and-or on a value of derivative to the function Φ(E) / E. In the table 5 and in figure 1 are presented curve of neutron gas temperature (Tn) as function of spectrum rigidity z for the first type of homogeneous infinite mediums.

Table 5.Values F_t, f_{epi}, z, and Tn for different compositions.
Normalization F_t and f_{epi} arbitrary

Graphite + absorber				Water + absorber			
Ft	fepi	z	Tn	Ft	fepi	z	Tn
10,18	14,80	0,69	1581,5	0.417	0.718	0.58	801.0
18,76	15,09	1,24	1152,4	2.715	0.770	3.53	448.2
44,94	15,51	2,90	675,2	4.456	0.775	5.75	405.5
66,28	15,62	4,24	561,7	5.316	0.776	6.85	387.9
82,04	15,66	5,24	520,2	6.497	0.778	8.35	374.7
147,92	15,74	9,40	438,7	8.359	0.780	10.72	360.5
287,54	15,78	18,22	379,4	12.700	0.781	16.27	345.2
522,05	15,80	33,03	349,0	19.154	0.782	24.48	329.3
1101,20	15,81	69,64	327,6	22.660	0.783	28.93	320.8

Comparisons of Tn(z). Data of comparisons for six variants of an estimation of dependence Tn(z) for model of temperature of neutron gas (3) Tn(z) = *a* / z + *b*
where 0,5 <z <75,0 are presented below:

1 – вБ1 – calculation under program MCU-RFFI of compositions water and an absorber.

2 – вК – calculation under the program the ASTRA of the same compositions with use of velocities of the reactions calculated by program MCU-RFFI.

3 – гБ1 – calculation of program MCU-RFFI for compositions graphite and an absorber.

4 – гК – calculation of the same compositions under the program the ASTRA with use of velocities of the reactions designed by program MCU-RFFI (variant the closest to experimental dependence).

5 – гБ2 – the second medium calculation by program MCU-RFFI of a composition with graphite.

6 – вБ2 – the second medium calculation by program MCU-RFFI of a composition with water.

The values of factors *a* and *b* are submitted in table 6.

Table 6. Value of factors *a* and *b*.

	Variant	*a*	*b*
1	вБ1	693,5	302,0
2	вК	1860,5	278,6
3	гБ1	1304,2	303,7
4	гК	1862,9	278,4
5	гБ2	891,4	344,9
6	вБ2	288,1	319,2

The factors, which are submitted in table 6, are show:
for variants вК and гК, values of factors *a* and *b* calculated under the programs are coincide,
for variants вБ1 and гБ1, and also вБ2 and гБ2 factors *a* and *b* considerably differ,
for variants вБ1 and вБ2 – factors *a* and *b* noticeably differ from each other,
for variants гБ1 and гБ2 – factors *a* and *b* differ considerably.

It is possible to note significant difference spectra in water from spectra in graphite and experimental spectra by the factors. That can speak about dependence of the factors for different compositions on mediums with fissing materials.

The curves $T(z) = a / z + b$ were calculated on all factors presented in the table 6. The statistical analysis of the goodness of fit and correlation pairs the curves been carried out which has shown, that:

– correlation on Person and Spearman – all pairs curves are correlated (are invariant concerning a normalization and displacement in a plane (x, y));

– test of Smirnov - Kolmogorov - distributions of pairs do not coincide (maximum differences of elements are great);

– t-test of Student proves to be confirming the goodness of fit for means and residuals of models with a value 0 (for means differences statistically insignificance and are close to 0);

– sign test - does not confirm the goodness of fit for distributions for pairs of curves on a term by term subtraction of values (y-x) (amounts of positive and negative values considerably differ);

- means for curves of term by term rations for two curves (y/x) differs from unit no more than on 20 % that means existence of insignificant differences of means;

- the factor a1 models $y = a1\ x + a0$ varies essentially except for variants вК – гК (for example, curves x and y in 1-5 times differ on a normalization);

- distribution of residuals of models $y = a1\ x + a0$ - does not correspond to normal distribution.

Adequacy of parameters F in Westcott's model and F_t in model (2) was investigated with application of codes MCU [9, 10] and the ASTRA [1, 4]. With this purpose under program MCU spectral parameters have been analyzed two types of fuel systems with different moderators (See section 4). For each type variants of the rigidity of a spectrum were ensured. On values of velocities of the reactions calculated by program MCU, values of the same parameters under the program the ASTRA were calculated.

Difference is observed for the rigid spectra, which it is possible to explain:
- smaller exactitude of the applied method in the area of small values z,
- different behavior Tn (z) for different the fuel systems, not exhibited at experiments,
- use of dependence Tn (z) in the code ASTRA for experimental data.

Arguments for the benefit of adequacy of parameters F in Westcott's model and F_t in model (2) are good for data of variants вК, гБ1 and гК in section 4.

Dependence of transition function D(E, T) from an energy for some values z in interval of energies of neutrons from 0,15 eV up to 1,0 eV for graphite are presented in figure 3. Our investigations of the spectrum area show that for rigidity < 5 length the area is negligible.

Dependences of spectral indexes on the rigidity of spectrum in graphite for the nuclides included UKD are submitted in figure 4. By comparison curves of the dependences for experiments and modeling is show that its differences are not principal.

CONCLUSIONS

The results carried out for the researches, confirm validity of the made suppositions that for "cold" mediums with fissing materials there is possibility:
- to uses of parametrical model of a spectrum for thermal and epithermal areas of energies;
- to determine parameters of spectrum F_t, f_{cpi} and Tn with help of the method.

Estimation of boundary of transitional area of a spectrum was produced by the method. That allows is justified to assume about insignificant length of transitional area for values of the rigidity of a spectrum z <5.

Existence of dependence of spectral indexes from z and Tn is shown, that allows producing an estimation of temperature of neutron gas by activation measurements. The dependence Tn (z) may be individual for each composition of a fuel lattice. However, it is possible to suppose, that with small error using the dependences of experimental data and graphite in areas with the rigidity of a spectrum z > 5 is supposed. At spectra with the rigidity less 5, apparently, with a small error it is possible to use a curve for water.

Application of the method, enough exact and not expensive, ensures:

- operative measurement of absolute values of neutron spectrum parameters at nuclear installations and in mediums generating neutrons;
- use of the detectors on various nuclear installations;
- comparison and-or verification of spectral calculating codes;
- use compact calibrated UKD for operative measurements;
- carrying out of measurements at not high fluency for activation of detectors (up to 10^{11} n/sm^{2}c) and radiation loadings.

Authors consider, that using of the method is sufficient for operational, not metrological measurements of neutron spectrum parameters.

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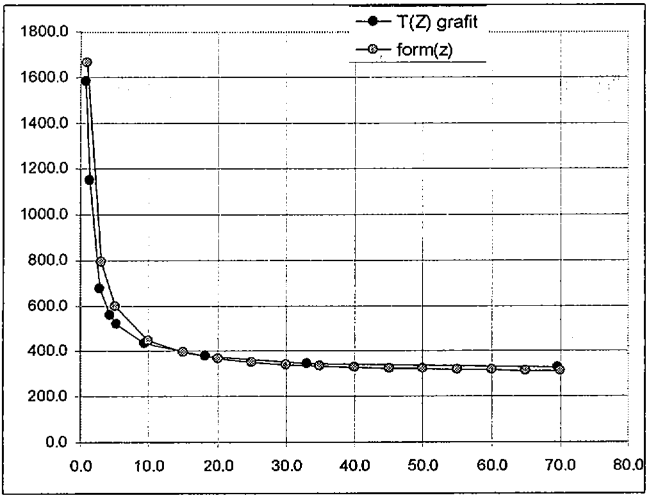

Fig. 1. Dependence of temperature of neutron gas (Tn) from a rigidity of a spectrum (z) for graphite. Approximation is Tn(z) =a / (z+b) + c, where a=1580, b=0,15 and c=290.

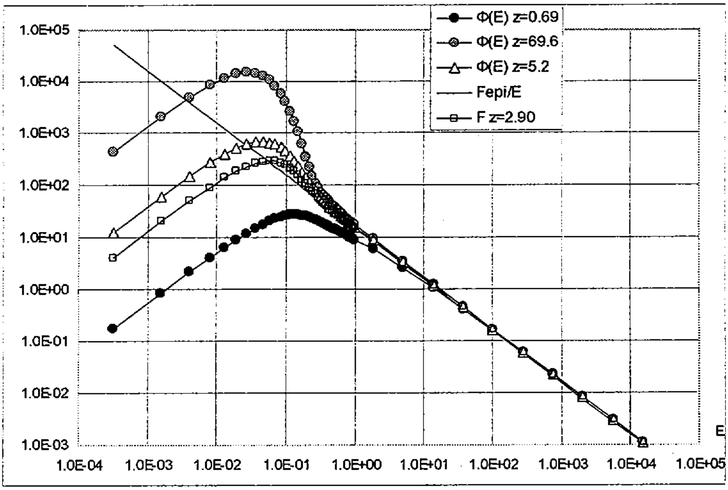

Fig. 2. Energy neutron spectra as function on rigidity for graphite.

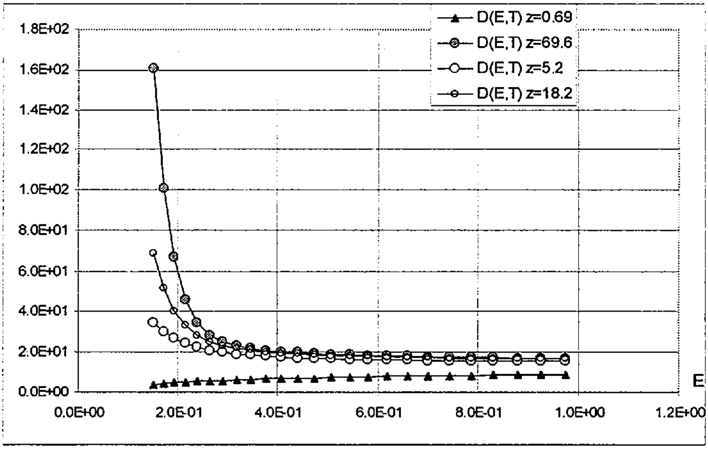

Fig. 3. A transition function Δ(E, T) in interval of neutron energy of from 0,15 eV up to 1,0 eV for graphite.

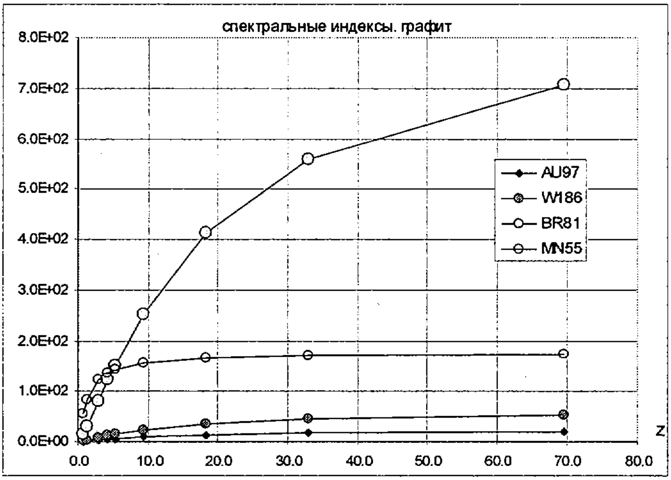

Fig. 4. Dependences of spectral indexes on rigidity in graphite for the nuclides included UKD