A new approach to reconstructing the neutron spectra of reactor facilities on the basis of activation measurements is proposed and investigated. A new parameterization of a neutron spectrum is introduced; this representation is in the form of a special “neutron” spline. A generalized algorithm for minimizing the directed deviation is used for the reconstruction. To analyze the possibilities of the approach developed, the spectra of the BARS-5, IGRIK, and YaGUAR reactor facilities are reconstructed on the basis of activation measurements. The reconstructed spectra agree well with previous results.

The determination of neutron spectra $\varphi(E)$ on the basis of activation measurements ordinarily reduces to solving a system of integral equations of the form [1, 2]

$$Q_i = \int_0^\infty \sigma_i(E)\varphi(E)dE, \quad i = 1, \ldots, N,$$

(1)

where $Q_i$ is the number of reactions on a nucleus of the main isotope of the $i$th indicator, measured with absolute standard error $\Delta Q_i (1\sigma)$; $E$ is the neutron energy; $\sigma_i(E)$ is the activation cross section of the $i$th indicator; $i$ is the number of the indicator; and $N$ is the number of indicators used in the measurements. The existence of a solution of the (1) problem is guaranteed by its physical content, but it is well known that it is an improperly posed problem [1–3]. The many methods existing for finding a solution differ by the form and method of introduction of a priori information. Thus, together with the fact that the solution sought must be positive, the requirements that $\varphi(E)$ be smooth and close to a certain trial function $\varphi^0(E)$, and so forth are often imposed [1–4].

We note that a great deal of significance has always been attached at the All-Russia Research Institute of Theoretical Physics to the choice of the initial approximation for the neutron spectrum $\varphi^0(E)$. For this, it was calculated by the Monte Carlo method for each specific case of measurement of a neutron spectrum. A suitable choice of $\varphi^0(E)$ is especially important in the energy range $10 \text{ keV} \leq E \leq 0.6 \text{ MeV}$; this is due mainly to the inadequacy of the information which sets of activation indicators provide in this region of the spectrum.

A group representation of the spectrum $\varphi(E)$ is often used to solve the (1) problem, and the problem reduces to solving a system of linear algebraic equations. Since the cross-sections of many activation reactions are of a resonance character, the number of groups must be large so that the quadrature error due to the transition to a system of equations would be small compared with the measurement errors $\Delta Q$. As a result, the uncertainty (or degeneracy) of the system is large. It has been proposed on the basis of a priori considerations concerning the typical reactor spectrum that a prescribed set of model functions or a piecewise representation of the neutron spectrum be used to decrease the number of parameters sought [4, 5].
this, the spectrum is partitioned on the energy scale into several characteristic parts, on each of which an appropriate analytical expression is used for $\phi(E)$ with undetermined coefficients. Thus, the spectrum of thermal and superthermal neutrons is written in the form

$$
\phi(E) = \begin{cases} 
C_1 E \exp\left(-E/T\right), & 0 \leq E < E_1; \\
C_2 / E, & E_1 \leq E \leq E_2,
\end{cases}
$$

where the unknowns are the parameters $C_1$, $T$, $C_2$, $E_1$, and $E_2$. Other analytical expressions are used for intermediate-energy and fast neutrons [5]. It is also noted in other works that the neutron spectrum of fast reactor facilities is close to a fission spectrum, which the following formula describes to within 10% [6]:

$$
\phi(E) = 0.77 \sqrt{E} \exp\left(-0.776E\right).
$$

Moreover, it is proposed in [7] that a two-component representation of the neutron spectrum

$$
\phi(E) = a_1 \phi_1(E) + a_2 \phi_2(E)
$$

as a combination of a Maxwell spectrum (for the fission neutrons) and the spectrum for inelastically scattered neutrons

$$
\phi_1(E) = \frac{2\alpha_1^{3/2}}{\sqrt{\pi}} \sqrt{E} \exp\left(-\alpha_1 E\right);
$$

$$
\phi_2(E) = \alpha_2^2 E \exp\left(-\alpha_2 E\right)
$$

with a small (only four) number of unknown parameters $\alpha_1$, $\alpha_2$, $a_1$, and $a_2$ be used in the in-core regions of reactors with a metal core. For completeness, we also note that the function [8]

$$
\phi(E) = \begin{cases} 
0.6680 \sqrt{E} \exp\left(-0.704E\right), & 0 < E < 6; \\
0.7947 \sqrt{E} \exp\left(0.734E\right), & E \geq 6
\end{cases}
$$

is a good fit to the neutron spectrum of a californium source, used as a standard in many countries.

The unknown parameters in the approximations presented above are chosen so that the spectrum as a whole would be a continuous function. If the number of parameters is less than the number of activation detectors, the problem of searching for them can formally become properly posed. As noted in [5], this method permits reconstructing a spectrum when the number of integral detectors is small and it is suitable for a wide but still limited number of desired spectra. In this approach, the desired spectrum $\phi(E)$ largely depends on how successful the choice of analytical expressions in each part of the energy scale is. In addition, the problem becomes nonlinear with respect to the parameters sought; this makes it difficult to solve.

It is noted in the handbook [6] that the method of representing a spectrum by a linear combination of prescribed functions does not provide adequate accuracy in reconstructing spectra. Acceptable results are obtained only in cases where the system of base functions is nearly complete with respect to the spectrum under investigation. Consequently, when switching from one class of spectra under investigation to another, a new system of base functions must be found.

In the present article, a new approach to reconstructing neutron spectra on the basis of a generalized algorithm for the method of minimizing the directed deviation is proposed and investigated [9]. The parameterization of the neutron spectrum, which is represented as a specialized “neutron” spline, is different from that used in previous works. The introduction of a neutron spline makes it possible to decrease the number of unknown parameters substantially.

We note that even in the new approach a priori information about the desired spectrum is largely obtained from preliminary calculations, performed by the Monte Carlo method, taking account of the material composition, the construction of an assembly, and the placement of the detectors. The importance of the latter fact is noted in the review [10].