MULTIGROUP CALCULATIONS OF CRITICAL AND FUEL ASSEMBLIES TAKING ACCOUNT OF SCATTERING ANISOTROPY

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A method for calculating reactor lattices by means of passage probabilities taking account of scattering anisotropy is extended to the multigroup case. The computed multiplication coefficients and the power-release distribution are essentially just as accurate as the Monte Carlo values if the errors due to the effective multigroup constants are removed. Apparently, the proposed method will be more effective for determining small difference effects.

The methods proposed previously for performing two-dimensional calculations of reactor lattices by passage probability methods were limited to the single-group approximation [1, 2]. However, in single-group approximations it is difficult to indicate the flux accuracy required because in practice the characteristics determined by the behavior of neutrons in the entire energy range are of greatest interest. The present paper gives the results of 48-group calculations performed by the passage probability method for some ZR-6 lattices [3] and a model of VVÉR-1000 fuel assemblies in different states.

The fluxes $\Phi$ in the azimuthal subzones $k$ of the zones $i$ of a cell $j$ are determined iteratively using balance equations for the current $J_{\text{in}}$ entering a cell and the current $J_{\text{out}}$ leaving a cell at the boundary between the cells $j$ and $j'$, adjoining one another along the sides $s$ and $s'$. For an energy group

$$J_{\text{in}}^{i,j,s} = J_{\text{out}}^{j',s'}, J_{\text{out}}^{j,s} = J_{\text{in}}^{i,j',s'};$$

$$V_{i,k} \Sigma_i \Phi_{i,k} = \sum_{i',k'} V_{i',k'} Q_{i',k',k} P_{i',k'\rightarrow i,k} + \sum_s J_{\text{in}}^{i,j,s} P_{i,s\rightarrow i,k};$$

$$J_{\text{out}}^{s} = \sum_{i,k} V_{i,k} Q_{i,k} P_{i,k\rightarrow s} + \sum_{s'} J_{\text{in}}^{i,j,s} P_{i',s'\rightarrow s};$$

(1)

where the neutron source in the group $n$ is given by the expression

$$Q_{i,k,n} = \sum_{n'} \Sigma_{s,i,n'\rightarrow n} \Phi_{i,k,n'} + \varepsilon_n \sum_{n'=1}^{48} v\Sigma_{f,i,n'} \Phi_{i,k,n'}.$$

Here $V_{i,k}$ is the subzone volume; $\Sigma_i$ is the total cross section; $\Sigma_{s,i}$ and $v\Sigma_{f,i}$ are, respectively, the scattering and generation cross sections. Numerical integration is used to calculate the multigroup probabilities $P$ for collisions, passage, and exit. In all groups, the previously determined auxiliary geometric information (the coordinates of points of intersection, the length of chord segments, and so on) is used for each type of cell.
The angular dependence of the fluxes (sources) in a subband has the form

$$\Phi(\mu, \chi, \nu) = \sum A_q \Phi_q \int_{P_1}^{P_3} H_{p}^{m}(\gamma) \mu = \cos \theta,$$

where $\theta$ is the angle between the direction of motion of a neutron and the Z axis; $A_q$ is a coefficient which is needed to make the harmonics orthonormal to one another. The functions $H$ describe the anisotropy of the macroscopic and microscopic flux distributions. In the first case, $H_{p}^{m}(\gamma) = \exp(i m \chi)$, where $\chi$ is the angle between the projection of neutron motion on the $X$–$Y$ plane and the $X$ axis (the axes $X$, $Y$, and $Z$ are common to all cells); in the second case, $H_{p}^{m}(\gamma) = \cos m \nu$, where $\nu$ is the angle between this projection and the direction to the center of the cell. The currents on the sides of the cells in Eq. (1) are divided into $N_a$ spatial segments and $N_\phi$ and $N_\theta$ angular sectors where they are assumed to be constant and to correspond to isotropic unilateral fluxes.

The basic positions are actually identical to the positions adopted in the probabilistic method of discrete ordinates \[4, 5\], having some advantages in solving problems of transmission of neutrons from an external source, calculating heterogeneous cells and reactors, and others.

The initial data are 48-group macroconstants formed in lattice calculations using the TVS-M computer program \[6\]. In this program, the thermalization of neutrons below 0.5 eV is described in 24 energy groups. The transition from the transport to the $P_1$ approximation is made using the data from the BNAB and KORT libraries, which are incorporated in TVS-M. The anisotropy of scattering by hydrogen above 1 eV is described in the $P_3$ approximation. It should be noted that the constants base of the TVS-M program is the same as that of the MCU-RFFI program \[7\], which implements the Monte Carlo method. In it, the scattering anisotropy due to the transition from the center-of-mass to the laboratory system (except for hydrogen in the thermal range) is described exactly, the scattering anisotropy in the center-of-mass system is taken into account in the $P_1$ approximation. The anisotropy of scattering by hydrogen below 1 eV is also described in the $P_1$ approximation. Taking this into account, the results of Monte Carlo calculations are viewed as test calculations; the differences are described by the approximations used in the calculations performed by the passage probability method.

Results. The extensive benchmark experiments performed on the ZR-6 critical assembly, built in 1974 for investigating VVÉR physics as part of a temporary international team of specialists from seven countries (members of the Council for Mutual Economic Aid), provide a convenient basis for the calculations \[3\]. The six chosen lattices with spacing 1.27 cm differ at room temperature by enrichment, the number of fuel elements, and absorbing elements, or the concentration of boric acid (Fig. 1). The calculations performed by the passage probability method with the orders of description of scattering anisotropy in the fuel and moderator $P_1$ and $P_3$, respectively, come closest to the Monte Carlo calculations (Table 1). The leakage at the ends of each lattice was estimated from the Monte Carlo calculations (two-dimensional and infinite height). The neutron multiplication coefficients differ by not more than 0.2%. The differences are the same for individual fuel cells. The appreciable underestimation of the multiplication coefficient of assemblies with absorbing elements could be due to the inadequacy of the $P_1$ approximation in the thermal range. For $E > 1$ eV, the $P_2$ approximation is exact for hydrogen, and the