DEPENDEne OF THE PARAMETERS OF ELECTRONUCLEAR MULTIPLICATION UPON ADMixed 239Pu AND 235U

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The yield of plutonium nuclei, the heat liberation, and other parameters of the electronuclear process were determined for natural and enriched uranium in all the work done to date. But considerable quantities of 239Pu can accumulate in an electronuclear reactor, and this significantly increases the number of low-energy fissions and, hence, the plutonium winning rates and the energy liberation. When the fuel of fuel elements is regenerated with the aid of the electronuclear process, the irradiated material is highly enriched also with the readily fissionable 235U nuclei.

The goal of the present work is to determine the influence of various degrees of 239Pu and 235U enrichment upon the electronuclear multiplication of neutrons.

The Monte Carlo technique was used for the calculations and resonance-type self-shielding of the cross sections was taken into account in a subgroup approximation. The calculations and the geometrical features of the six-component reactor were the same as in [1, 2]. The reactor had a diameter of 120 cm and a length of 90 cm. The proton beam was directed onto a narrow 26 cm long axial slit and was incident on a lead target having a diameter of 8 cm. The chemical composition of the homogenized electronuclear reactor beyond the lead target was calculated with the equation 

\[ Z_i = \frac{V_i N_i}{\sum_{j=1}^{I} V_j N_j} \]

where \( V_i \) denotes the volume occupied by an element; \( N_i \) denotes the number (in %) of nuclei of the \( i \)-th element per cm\(^3\), namely: \( ^{238}\text{U} + 23\text{Pu} \) or \( ^{238}\text{U} + 23\text{U} \); \( ^{56}\text{Fe} \); \( ^{23}\text{Na} \); and \( ^{16}\text{O} \). The total concentration of the material undergoing fission in the reactor was assumed to be constant; only the relative concentrations of the \( ^{238}\text{U} \) and \( ^{239}\text{Pu} \) or \( ^{235}\text{U} \) nuclei were changed:

\[ \eta = \frac{N(X)}{N(\text{X}^{238}\text{U}) + N(\text{X}^{239}\text{Pu})} = \frac{(\text{238}/A_x \alpha)}{1 + \alpha (\text{238}/A_x - 1)} = \frac{238}{A_x \alpha}, \]

where \( \alpha = \rho(X)/[\rho(^{238}\text{U}) + \rho(X)] \), \( \rho(X) \), \( N(X) \), and \( A_x \) denote the density, the number of nuclei, and the mass number of the element \( X \), respectively.

When the concentration of \( ^{239}\text{Pu} \) and \( ^{235}\text{U} \) nuclei increases, the number of nuclear interactions of neutrons (nodal points of the cascade tree, see Table 1) increases sharply and the calculations become more involved. Since the number of high-energy interactions, which are most difficult to bring into account, remains almost constant (the properties of the plutonium and uranium nuclei hardly differ in regard to their response to high-energy particles [3]), and since the trajectories of low-energy neutrons are rapidly calculated when the technique of statistical weights is used, the total computation time hardly changes and amounts to about 20 min on an SDS-6500 computer for the first 100 1 GeV protons (100 cascade trees).

Enrichment with Plutonium. It follows from an analysis of Fig. 1 and Table 2 that the distribution of the capture reactions is almost independent of the enrichment, whereas the maximum of the fission reactions is shifted toward layers farther away from the reactor center when the plutonium concentration rises. This is a consequence of the fact that plutonium fission results predominantly from very slow neutrons the number of which increases at greater distances from the reactor axis. At \( \alpha = 2\% \), the ratio of the number of fissions of \( ^{238}\text{U} \) and \( ^{239}\text{Pu} \) nuclei is \( N_{20}/N_{29} = 1 \), whereas it is as high as 2.5 at \( \alpha = 6\% \).

The neutron yield per primary proton increases rapidly with increasing enrichment but the number of neutrons leaving the reactor increases even more rapidly. At \( \alpha = 6-8\% \) the number of such particles already amounts to half the number of all neutrons produced in the reactor. An even higher enrichment means that the plutonium winning rates are slowed down and at \( \alpha \geq 10\% \) (in the reactor geometry under consideration), the number of plutonium nuclei under going fission and radiative capture...
TABLE 1. Dependence of the Number of Elastic and Inelastic Interactions of Neutrons with Nuclei of Admixed $^{235}$U

<table>
<thead>
<tr>
<th>Parameter</th>
<th>0,3</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>10</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta, %$</td>
<td>0,3</td>
<td>2,03</td>
<td>4,05</td>
<td>6,07</td>
<td>10,1</td>
<td>12,1</td>
</tr>
<tr>
<td>$N_{el}$</td>
<td>2230</td>
<td>2540</td>
<td>3290</td>
<td>3570</td>
<td>5400</td>
<td>4690</td>
</tr>
<tr>
<td>$N_{in}$</td>
<td>115</td>
<td>140</td>
<td>185</td>
<td>220</td>
<td>360</td>
<td>350</td>
</tr>
</tbody>
</table>

**Remark:** The number of inelastic interactions includes $(n, \gamma)$ capture, fission, and inelastic $(n, xn)$ reactions with neutron generation: $N_{in} = N_c + N_f + N_n$.

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![Figure 1](image1.png)

**Fig. 1.** a) Radial and b) longitudinal distribution of the number $N_c$ of $(n, \gamma)$ capture reactions, of the number $N_f$ of fissions, and of the heat liberation $Q$ at an enrichment of 0.3 (U) (---), 2 (Pu) (---), and 6 (Pu) (······).

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is greater than the number of newly produced. In this case, the plutonium-winning system is converted into a powerful source of neutrons. The reactor must be surrounded with an uranium shield for winning plutonium (or with a shield of thorium for winning $^{233}$U). The angular distribution of the neutrons leaving the reactor is almost symmetric with respect to the axis of the