Evaluation of the burnout efficiency of Np-237 and Am-241 in a BN-600 reactor with a modified core

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Abstract. From the results of comparing the fission and capture cross sections, it follows that a reactor with fuel in the form of Am-241 or Np-237 can only be on fast neutrons, because in the thermal and intermediate spectra, the capture cross section significantly exceeds the fission cross section. Therefore, this paper analyzes the possibility of achieving criticality when loading the BN-600 reactor core with fuel from Am-241 or Np-237 alone, as well as the efficiency of their burning out in various modifications and variants of core loading. The calculation results show that when the reactor is fully loaded with fuel consisting of minor actinides of interest, we have a huge reactivity reserve, which does not decrease, and in some cases increases, during 450 days of reactor operation at rated power. Also, when calculating the modified core with fuel from minor actinides and uranium dioxide, it was possible to achieve high burnout rates of Am-241 and Np-237.

1. Introduction

Since the fuel spent in a nuclear reactor is a potential threat to the environment, it would be appropriate to develop the most efficient ways to burn it in existing industrial reactors. From the results of comparing the fission and capture cross sections (see figure 1), it follows that a reactor with fuel in the form of Am-241 or Np-237 can only be on fast neutrons, because in the thermal and intermediate spectra, the capture cross section significantly exceeds the fission cross section, so in this work it was decided to use the BN-600 reactor as a computational model.

In order to increase the proportion of burned-out actinide nuclei, it makes sense to create a core configuration in which the neutron flux will make the maximum contribution to the transmutation of the actinide under study. Based on this, we assumed that the most efficient burning of Am²⁴¹/Np²³⁷ can be achieved by "diluting" the fast spectrum with lower-energy neutrons, where fast neutrons will lead to fission, and thermal and intermediate neutrons to transmutation with possible further fission. To achieve this purpose, the BN-600 reactor core was modeled in various variations using the SERPENT 2.1.30 software package, as well as geometric parameters and data on the isotopic composition of structural materials from works [1-3].
2. Description of calculation models

While working on the study, three different layouts of the bn-600 reactor core were modeled (for further simplification, the name of each model is indicated in parentheses):

1. reactor core fully loaded with fuel from Am\textsuperscript{241}/Np\textsuperscript{237} ("Full Am\textsuperscript{241}/Np\textsuperscript{237}");
2. standard fuel assemblies in the Central zone of the reactor were replaced with fuel assemblies with fuel from Am\textsuperscript{241}/Np\textsuperscript{237} ("Center Am\textsuperscript{241}/Np\textsuperscript{237}");
3. central zone of the reactor consists of a fuel assembly with fuel from Am\textsuperscript{241}/Np\textsuperscript{237}, the fuel assembly consists of beryllium blocks, inside which are placed fuel cells from Am\textsuperscript{241}/Np\textsuperscript{237} ("Ring Am\textsuperscript{241}/Np\textsuperscript{237}"). [4-5]

The following materials were considered as fuel: americium metal (neptunium) and americium dioxide (neptunium).

In «Ring» model, boron carbide (B\textsubscript{4}C) was placed on the periphery of the experimental area as a thermal neutron absorber to prevent neutron flux mitigation in standard fuel assemblies.

The main design characteristics are presented below (see table 1).

| Characteristic                                      | Value     |
|----------------------------------------------------|-----------|
| Heat output, MW                                     | 1470      |
| The average fuel temperature, K                    | 1500      |
| The average temperature of the coolant, K          | 600       |
| Estimated operating time of the reactor at stationary power, days | 450       |
| Fuel:                                              |           |
| Uranium dioxide                                    | 8.5 g/cm\textsuperscript{3} |
| Metal americium-241                                | 13.65 g/cm\textsuperscript{3} |
| Metallic neptunium-237                             | 20.25 g/cm\textsuperscript{3} |
| Americium dioxide-241                              | 11.68 g/cm\textsuperscript{3} |
| Neptunium dioxide-237                              | 11.1 g/cm\textsuperscript{3} |

Used nuclear data library – JEFF-3.1.1

When constructing the calculation models, the heterogeneous structure was taken into account only for fuel assemblies in terms of the height of the fuel column, and control rods were excluded from the calculation. The following diagrams show the radial (see figure 2) and axial (see figure 3) locations of elements of the BN-600 core design models, as well as the diagrams of core cells (see figure 4). Figure 2a shows the "Center Am\textsuperscript{241}/Np\textsuperscript{237}" model, and figure 2b shows the "Ring Am\textsuperscript{241}/Np\textsuperscript{237}" (the «Full
Am$^{241}$/Np$^{237}$» model is similar to the model shown in figure 2a, but fuel assemblies with uranium fuel have been replaced with actinide fuel assemblies).

**Figure 2.** Radial layout of BN-600 core elements in the studied models:
1. radial reflectors; 2-3. steel shielding; 4. FAs HEZ (26% $^{235}$U); 5. FAs MEZ (21% $^{235}$U); 6. control rods; 7. FAs with fuel from Am$^{241}$/Np$^{237}$; 8. beryllium blocks with fuel cells from Am$^{241}$/Np$^{237}$.

**Figure 3.** Axial layout of BN-600 core elements in the studied models:
1 – axial reflector;
2 – cones;
3 – upper boron shield;
4 – sodium plenum;
5 – plugs;
6 – core;
7, 8 – axial blanket 1,2;
6, 7, 8 – core for fuel assemblies with fuel from Am$^{241}$/Np$^{237}$. 
Figure 4. The layout of elements in cells of the reactor core:
a – regular FA; b – cells in the "Ring" calculation model (figure 2b);
1 – hexagonal wrapper; 2 – beryllium block; 3 – cladding (δ = 0.4 mm);
4 – fuel (d = 6.1 mm); 5 – absorber at the boundary of the study region (B₄C
with 25% B¹⁰ enrichment).

3. Analysis of calculation results
For computational studies, we used the SERPENT program code [6-8], which implements the Monte-
Carlo method. It provides the ability to calculate criticality, account for changes in the isotopic
composition of fuel during the operation of a nuclear reactor, and track the neutron flux.

3.1. Metal fuel
Figure 5 shows the change in the $K_{\text{eff}}$ of the calculated systems (for comparison, a graph of the change
in $K_{\text{eff}}$ for the standard load of the BN-600 is shown). The results show quite an interesting effect.
Despite the fact that for the "Center" and "Full" models we already have a huge reactivity reserve,
the value of $K_{\text{eff}}$ for models with a full load of fuel from minor actinides is constantly increasing during the
estimated time, and for other models, $K_{\text{eff}}$ increases at the beginning of irradiation, and then falls. The
explanation is related to the produced isotopes, which are more effective in contributing to the
multiplication coefficient than the original Am-241 or Np-237. Thus, there is an effect of reproduction
of a new fuel, which is obtained not from a special raw material such as U-238, but from the same Np-
237, which did not split, but captured a neutron, then decayed into Pu-238, and so on. This effect requires
a separate study.
Due to the fact that the model of the standard core of the BN-600 reactor was changed for the study, we are interested in how the distribution of the neutron flux over the core radius changed (see figure 6 and figure 7).

**Figure 5.** Graph of $K_{\text{eff}}$ changes in the studied models.

**Figure 6.** Distribution of the neutron flux density over the core radius in the studied models.
Figure 7. Distribution of the thermal (up to 1 eV) neutron flux density over the core radius in the studied models.

This behavior of the neutron flux density for the "Center" and "Ring" models is due to the fact that the neutron yield is higher for fission of Am\(^{241}\) and Np\(^{237}\) than for fission of U\(^{235}\). Moreover, in the "Ring" model, central part is surrounded by beryllium blocks that act as a reflector and moderator (this can be seen from the graphs in figure 7).

Table 2-4 shows the results of calculating changes in the nuclide composition of Am-241 fuel from the time of fuel irradiation in each of the calculated models. As we can see, the greatest decrease in the concentration of Am-241 occurs in the "Ring" model, namely in the third ring – fuel assemblies with beryllium blocks (about 80% of the initial concentration of Am-241 nuclei was separated or mutated). A significant increase is seen in comparison with other Pu-238 nuclides, followed by Pu-242.

Almost the same situation is observed in models with fuel from Np-237 (see table 5-7), where the maximum change was 63% of the initial concentration of Np-237.

Table 2. Change in the nuclide composition of metal fuel from Am-241 in the «Full Am\(^{241}\) » model.

| Nuclei | Am\(^{241}\) | Am\(^{241d}\) | Am\(^{241m}\) | Np\(^{239\text{m}}\) | Np\(^{239}\) | Pu\(^{239}\) | Pu\(^{239m}\) | Pu\(^{240}\) | Pu\(^{240m}\) | Np\(^{237}\) | U\(^{235}\) |
|--------|--------------|-------------|-------------|-----------------|-------------|-----------|-----------|-----------|-----------|-------------|-------|
| Time, days | Ring 1 | | | | | | | | | | |
| 0 | 4.1002E+22 | 6.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
| 10 | 3.3180E+22 | 3.0500E+19 | 3.7240E+18 | 1.3400E+17 | 3.3270E+16 | 1.3400E+15 | 4.9900E+15 | 5.3000E+15 | 5.4400E+15 | 0.0000E+00 | 0.0000E+00 |
| 180 | 1.2700E+16 | 6.1000E+15 | 3.7010E+15 | 5.9600E+14 | 1.7800E+14 | 5.9600E+13 | 2.2400E+13 | 2.3100E+13 | 2.5300E+13 | 0.0000E+00 | 0.0000E+00 |
| 270 | 1.2100E+16 | 6.1000E+15 | 3.7010E+15 | 5.9600E+14 | 1.7800E+14 | 5.9600E+13 | 2.2400E+13 | 2.3100E+13 | 2.5300E+13 | 0.0000E+00 | 0.0000E+00 |
| 360 | 1.1100E+16 | 6.1000E+15 | 3.7010E+15 | 5.9600E+14 | 1.7800E+14 | 5.9600E+13 | 2.2400E+13 | 2.3100E+13 | 2.5300E+13 | 0.0000E+00 | 0.0000E+00 |
| 450 | 1.0600E+16 | 6.1000E+15 | 3.7010E+15 | 5.9600E+14 | 1.7800E+14 | 5.9600E+13 | 2.2400E+13 | 2.3100E+13 | 2.5300E+13 | 0.0000E+00 | 0.0000E+00 |
| Time, days | Ring 2 | | | | | | | | | | |
| 0 | 4.1000E+22 | 2.0820E+19 | 3.6630E+18 | 1.2920E+17 | 3.1330E+16 | 5.9820E+15 | 1.9010E+15 | 1.9010E+15 | 1.9010E+15 | 0.0000E+00 | 0.0000E+00 |
| 10 | 3.3090E+22 | 3.0500E+19 | 3.7240E+18 | 1.3100E+17 | 3.7820E+16 | 5.8840E+15 | 1.7010E+15 | 1.7010E+15 | 1.7010E+15 | 0.0000E+00 | 0.0000E+00 |
| 180 | 1.2700E+16 | 6.1000E+15 | 3.7010E+15 | 5.9600E+14 | 1.7800E+14 | 5.9600E+13 | 2.2400E+13 | 2.3100E+13 | 2.5300E+13 | 0.0000E+00 | 0.0000E+00 |
| 270 | 1.2100E+16 | 6.1000E+15 | 3.7010E+15 | 5.9600E+14 | 1.7800E+14 | 5.9600E+13 | 2.2400E+13 | 2.3100E+13 | 2.5300E+13 | 0.0000E+00 | 0.0000E+00 |
| 360 | 1.1100E+16 | 6.1000E+15 | 3.7010E+15 | 5.9600E+14 | 1.7800E+14 | 5.9600E+13 | 2.2400E+13 | 2.3100E+13 | 2.5300E+13 | 0.0000E+00 | 0.0000E+00 |
| 450 | 1.0600E+16 | 6.1000E+15 | 3.7010E+15 | 5.9600E+14 | 1.7800E+14 | 5.9600E+13 | 2.2400E+13 | 2.3100E+13 | 2.5300E+13 | 0.0000E+00 | 0.0000E+00 |
### Table 3. Change in the nuclide composition of metal fuel from Am-241 in the «Center Am-241» model.

| Nuclide | Am-235 | Am-239 | Am-241 | Am-242 | Am-243 | Am-244 | Am-245 | Am-246 | Am-247 | Am-248 | Am-249 | Am-250 | Am-251 | Am-252 | Am-253 | Am-254 | Am-255 | Am-256 | Am-257 | Am-258 |
|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Ring 1  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Time, days | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0 |

### Table 4. Change in the nuclide composition of metal fuel from Am-241 in the «Ring Am-241» model.

| Nuclide | Am-235 | Am-239 | Am-241 | Am-242 | Am-243 | Am-244 | Am-245 | Am-246 | Am-247 | Am-248 | Am-249 | Am-250 | Am-251 | Am-252 | Am-253 | Am-254 | Am-255 | Am-256 | Am-257 | Am-258 |
|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Ring 1  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Time, days | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

### Table 5. Change in the nuclide composition of metal fuel from Np-237 in the «Full Np-237» model.

| Nuclide | Am-235 | Am-239 | Am-241 | Am-242 | Am-243 | Am-244 | Am-245 | Am-246 | Am-247 | Am-248 | Am-249 | Am-250 | Am-251 | Am-252 | Am-253 | Am-254 | Am-255 | Am-256 | Am-257 | Am-258 |
|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Ring 1  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Time, days | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |


Table 6. Change in the nuclide composition of metal fuel from Np-237 in the «Center Np237» model.

| Nuclide | Np237 | Np239 | Am241 | Am242 | Am244 | Pu239 | Pu240 | Pu242 | Pu244 | Pu246 | Pu248 | Pu250 | Pu252 | L216 | L22
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Time, day |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 0       | 5.144E+12 | 6.0000E+00 | 6.0000E+00 | 6.0000E+00 | 6.0000E+00 | 3.4000E+00 | 9.3000E+00 | 1.2000E+00 | 2.5000E+00 | 1.6000E+00 | 8.6000E+00 | 3.9000E+00 | 1.2000E+00 | 6.0000E+00 | 1.0000E+00 | 6.0000E+00 | 1.2000E+00 |
| 90     | 4.733E+12 | 2.679E+09 | 2.610E+10 | 6.126E+09 | 1.374E+09 | 1.673E+09 | 1.832E+09 | 7.400E+08 | 1.770E+08 | 1.630E+08 | 1.510E+08 | 1.420E+08 | 1.330E+08 | 1.240E+08 | 1.150E+08 | 1.060E+08 | 9.700E+07 |
| 180    | 4.444E+12 | 8.615E+11 | 9.347E+12 | 6.085E+12 | 1.276E+11 | 2.327E+10 | 3.624E+09 | 1.046E+10 | 1.276E+09 | 1.626E+09 | 1.276E+09 | 1.046E+09 | 7.900E+08 | 5.500E+08 | 2.200E+08 | 6.700E+07 | 3.000E+07 |
| 270    | 3.738E+12 | 1.497E+09 | 1.328E+10 | 3.343E+09 | 5.060E+09 | 1.504E+10 | 1.584E+10 | 6.680E+09 | 7.980E+09 | 1.143E+10 | 1.374E+10 | 1.697E+10 | 1.921E+10 | 2.145E+10 | 2.369E+10 | 2.593E+10 | 2.817E+10 |
| 360    | 3.509E+12 | 4.395E+09 | 2.567E+10 | 7.460E+09 | 1.387E+10 | 2.932E+10 | 6.860E+10 | 1.607E+10 | 2.237E+10 | 2.818E+10 | 3.624E+10 | 4.227E+10 | 4.954E+10 | 5.680E+10 | 6.406E+10 | 7.132E+10 | 7.858E+10 |
| 450    | 3.286E+12 | 3.941E+09 | 7.825E+10 | 1.428E+10 | 1.124E+10 | 8.404E+10 | 3.175E+10 | 4.377E+10 | 5.786E+10 | 6.666E+10 | 7.679E+10 | 8.703E+10 | 9.729E+10 | 1.076E+10 | 1.178E+10 | 1.281E+10 | 1.383E+10 |

Table 7. Change in the nuclide composition of metal fuel from Np-237 in the «Ring Np237» model.

| Nuclide | Np237 | Np239 | Am241 | Am242 | Am244 | Pu239 | Pu240 | Pu242 | Pu244 | Pu246 | Pu248 | Pu250 | Pu252 | L216 | L22
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Time, day |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 0       | 5.144E+12 | 6.0000E+00 | 6.0000E+00 | 6.0000E+00 | 6.0000E+00 | 3.4000E+00 | 9.3000E+00 | 1.2000E+00 | 2.5000E+00 | 1.6000E+00 | 8.6000E+00 | 3.9000E+00 | 1.2000E+00 | 6.0000E+00 | 1.0000E+00 | 6.0000E+00 | 1.2000E+00 |
| 90     | 4.733E+12 | 2.679E+09 | 2.610E+10 | 6.126E+09 | 1.374E+09 | 1.673E+09 | 1.832E+09 | 7.400E+08 | 1.770E+08 | 1.630E+08 | 1.510E+08 | 1.420E+08 | 1.330E+08 | 1.240E+08 | 1.150E+08 | 1.060E+08 | 9.700E+07 |
| 180    | 4.444E+12 | 8.615E+11 | 9.347E+12 | 6.085E+12 | 1.276E+11 | 2.327E+10 | 3.624E+09 | 1.046E+10 | 1.276E+09 | 1.626E+09 | 1.276E+09 | 1.046E+09 | 7.900E+08 | 5.500E+08 | 2.200E+08 | 6.700E+07 | 3.000E+07 |
| 270    | 3.738E+12 | 1.497E+09 | 1.328E+10 | 3.343E+09 | 5.060E+09 | 1.504E+10 | 1.584E+10 | 6.680E+09 | 7.980E+09 | 1.143E+10 | 1.374E+10 | 1.697E+10 | 1.921E+10 | 2.145E+10 | 2.369E+10 | 2.593E+10 | 2.817E+10 |
| 360    | 3.509E+12 | 4.395E+09 | 2.567E+10 | 7.460E+09 | 1.387E+10 | 2.932E+10 | 6.860E+10 | 1.607E+10 | 2.237E+10 | 2.818E+10 | 3.624E+10 | 4.227E+10 | 4.954E+10 | 5.680E+10 | 6.406E+10 | 7.132E+10 | 7.858E+10 |
| 450    | 3.286E+12 | 3.941E+09 | 7.825E+10 | 1.428E+10 | 1.124E+10 | 8.404E+10 | 3.175E+10 | 4.377E+10 | 5.786E+10 | 6.666E+10 | 7.679E+10 | 8.703E+10 | 9.729E+10 | 1.076E+10 | 1.178E+10 | 1.281E+10 | 1.383E+10 |

3.2. Dioxide fuel

Figure 8 shows the change in the $K_{eff}$ of the calculated systems (for comparison, a graph of the change in $K_{eff}$ for the standard load of the BN-600 is shown).

Figure 8. Graph of $K_{eff}$ changes in the studied models.
Due to the fact that the dioxide fuel has a lower density than the metal fuel, there is a decrease in the reactivity margin in comparison with the calculations of models based on metal fuel. For the same reason, the behavior of $K_{eff}$ changes during reactor operation differs from the behavior in previous calculations.

Due to the fact that the model of the standard core of the BN-600 reactor was changed for the study, we are interested in how the distribution of the neutron flux over the core radius changed (see figure 9 and figure 10).

**Figure 9.** Distribution of the neutron flux density over the core radius in the studied models.

**Figure 10.** Distribution of the thermal (up to 1 eV) neutron flux density over the core radius in the studied models.

This behavior of the neutron flux density for the "Center Np$^{237}$" and "Ring Am$^{241}$/Np$^{237}$" models is difficult to explain, but I assume that this is due to a change in the fuel density (for neptunium almost 2 times), and this in turn is due to the concentration. In addition, the presence of oxygen nuclei in the fuel,
even if very small, allows neutrons to slow down, which can lead to the predominance of transmutation of the studied actinides over their fission. Plus, in the "Ring" model, central part is surrounded by beryllium blocks that act as a reflector and moderator (this can be seen from the graphs in figure 10).

Table 8 shows the results of calculating changes in the nuclide composition of Am-241 fuel from the time of fuel irradiation in each of the calculated models. As we can see, the greatest decrease in the concentration of Am-241 occurs in the "Ring" model, namely in the third ring – fuel assemblies with beryllium blocks (about 53% of the initial concentration of Am-241 nuclei was separated or mutated). A significant increase is seen in comparison with other Pu-238 nuclides, followed by Pu-242.

Almost the same situation is observed in models with fuel from Np-237 (see table 11-13), where the maximum change was 38% of the initial concentration of Np-237.

Table 8. Change in the nuclide composition of dioxide fuel from Am-241 in the «Full Am241» model.

| Nuclide     | Am241 | Am242 | Am243 | Am244 | Np237 | Np238 | Pu238 | Pu239 | Pu240 | Pu241 | Pu242 | L238 | L239 | L240 |
|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|------|
| Time, days  |       |       |       |       |       |       |       |       |       |       |       |      |      |      |
| Ring 1      |       |       |       |       |       |       |       |       |       |       |       |      |      |      |
| 0           | 2.576×10^-2 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 |
| 10          | 2.576×10^-2 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 |
| Ring 2      |       |       |       |       |       |       |       |       |       |       |       |      |      |      |
| 0           | 2.576×10^-2 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 |
| 10          | 2.576×10^-2 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 |

Table 9. Change in the nuclide composition of dioxide fuel from Am-241 in the «Center Am241» model.

| Nuclide     | Am241 | Am242 | Am243 | Am244 | Np237 | Np238 | Pu238 | Pu239 | Pu240 | Pu241 | Pu242 | L238 | L239 | L240 |
|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|------|
| Time, days  |       |       |       |       |       |       |       |       |       |       |       |      |      |      |
| Ring 1      |       |       |       |       |       |       |       |       |       |       |       |      |      |      |
| 0           | 2.576×10^-2 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 |
| 10          | 2.576×10^-2 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 |
| Ring 2      |       |       |       |       |       |       |       |       |       |       |       |      |      |      |
| 0           | 2.576×10^-2 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 |
| 10          | 2.576×10^-2 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 | 0.000×10^-0 |
Table 10. Change in the nuclide composition of dioxide fuel from Am-241 in the «Ring Am 241» model.

| Nuclide | Am²⁴¹ | Am²⁴² | Am²⁴³ | Am²⁴⁴ | Am²⁴⁵ | Am²⁴⁶ | Am²⁴⁷ | Am²⁴⁸ | Am²⁴⁹ | Am²⁵⁰ | Am²⁵¹ | Am²⁵² | Am²⁵³ | Am²⁵⁴ | Am²⁵⁵ | Am²⁵⁶ | Am²⁵⁷ | Am²⁵⁸ | Am²⁵⁹ | Am²⁶⁰ | Am²⁶¹ | Am²⁶² | Am²⁶³ | Am²⁶⁴ | Am²⁶⁵ | Am²⁶⁶ | Am²⁶⁷ | Am²⁶⁸ | Am²⁶⁹ | Am²⁷⁰ | Am²⁷¹ | Am²⁷² |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|         |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |

Table 11. Change in the nuclide composition of dioxide fuel from Np-237 in the «Full Np ²³⁷» model.

| Nuclide | Np²³⁷ | Np²³⁸ | Np²³⁹ | Np²⁴⁰ | Np²⁴¹ | Np²⁴² | Np²⁴³ | Np²⁴⁴ | Np²⁴⁵ | Np²⁴⁶ | Np²⁴⁷ | Np²⁴⁸ | Np²⁴⁹ | Np²⁵⁰ | Np²⁵¹ | Np²⁵² | Np²⁵³ | Np²⁵⁴ | Np²⁵⁵ | Np²⁵⁶ | Np²⁵⁷ | Np²⁵⁸ | Np²⁵⁹ | Np²⁶⁰ | Np²⁶¹ | Np²⁶² | Np²⁶³ | Np²⁶⁴ | Np²⁶⁵ | Np²⁶⁶ | Np²⁶⁷ | Np²⁶⁸ | Np²⁶⁹ | Np²⁷⁰ | Np²⁷¹ | Np²⁷² |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|         |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |

Table 12. Change in the nuclide composition of dioxide fuel from Np-237 in the «Center Np ²³⁷» model.

| Nuclide | Np²³⁷ | Np²³⁸ | Np²³⁹ | Np²⁴⁰ | Np²⁴¹ | Np²⁴² | Np²⁴³ | Np²⁴⁴ | Np²⁴⁵ | Np²⁴⁶ | Np²⁴⁷ | Np²⁴⁸ | Np²⁴⁹ | Np²⁵⁰ | Np²⁵¹ | Np²⁵² | Np²⁵³ | Np²⁵⁴ | Np²⁵⁵ | Np²⁵⁶ | Np²⁵⁷ | Np²⁵⁸ | Np²⁵⁹ | Np²⁶⁰ | Np²⁶¹ | Np²⁶² | Np²⁶³ | Np²⁶⁴ | Np²⁶⁵ | Np²⁶⁶ | Np²⁶⁷ | Np²⁶⁸ | Np²⁶⁹ | Np²⁷⁰ | Np²⁷¹ | Np²⁷² | Np²⁷³ |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|         |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
Table 13. Change in the nuclide composition of dioxide fuel from Np\textsuperscript{237} in the «Ring Np\textsuperscript{237}» model.

| Nuclide | Np\textsuperscript{237} | Am\textsuperscript{241} | Am\textsuperscript{243} | Am\textsuperscript{244} | Pu\textsuperscript{239} | Pu\textsuperscript{240} | Pu\textsuperscript{241} | Pu\textsuperscript{242} | U\textsuperscript{235} | U\textsuperscript{238} |
|---------|-----------------|------------------|------------------|------------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Ring 1  | 0.000000000000  | 0.000000000000  | 0.000000000000  | 0.000000000000  | 0.000000000000  | 0.000000000000  | 0.000000000000  | 0.000000000000  | 0.000000000000  | 0.000000000000  |
| 90      | 2,645.7E+12     | 4,669.8E+12     | 1.021E+09       | 9.393E+08       | 6.726E+07       | 1.173E+08       | 4.157E+07       | 2.772E+07       | 1.057E+08       | 6.00000E+07     |
| 180     | 2.451E+13       | 8.090E+13       | 1.437E+09       | 8.387E+08       | 5.227E+07       | 1.085E+09       | 4.754E+07       | 2.931E+07       | 9.378E+08       | 5.09000E+07     |
| 270     | 2.416E+13       | 4.290E+13       | 3.742E+09       | 1.322E+08       | 8.51E+07        | 1.746E+09       | 4.419E+07       | 1.479E+08       | 5.716E+08       | 3.196E+08       |
| 360     | 2.383E+13       | 7.757E+13       | 1.959E+09       | 3.101E+08       | 2.322E+07       | 1.274E+10       | 8.471E+07       | 1.394E+09       | 5.864E+08       | 2.033E+08       |
| 456     | 2.312E+13       | 6.494E+13       | 8.419E+09       | 1.222E+08       | 9.287E+06       | 5.875E+09       | 6.09000E+06     | 2.331E+08       | 1.262E+08       | 1.337E+07      |

4. Conclusion

The advantages of implementing this approach to transmutation in comparison with traditional ones are quite obvious. So, if you use, for example, a reactor with uranium or MOX fuel for transmutation, then, in addition to burning out "foreign" minor actinides, it will additionally work out "its own". In the case of fuel from some minor actinides, the reactor will burn only "its own". [9-10]

The results of calculations showed that the BN-600 reactor can use fuel consisting only of Am\textsuperscript{241}/Np\textsuperscript{237}, while having a huge reactivity reserve.

It was also possible to achieve high Am\textsuperscript{241}/Np\textsuperscript{237} burnout rates in the "Ring" model, which is based on the assumption that the most effective burning of actinides can be achieved by "diluting" the fast spectrum with lower-energy neutrons, where fast neutrons will lead to fission, and thermal and intermediate ones to transmutation with possible further fission.

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