# Feasibility Analysis for LEU Conversion of the WWR-K Reactor Using an Eight-Tube Uranium Dioxide Fuel Assembly

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## ABSTRACT

The WWR-K research reactor presently uses HEU (36%) fuel. Results of analysis performed for several core configurations for the WWR-K reactor using thin-walled eight- and four-tube LEU fuel assemblies (FA) with uranium dioxide fuel of the mass density 2.8 g·cm$^{-3}$ are presented. Core configurations using light water and beryllium reflectors are considered. Reactor core characteristics such as excess reactivity, the reactivity worth of the CPS control rods, the operation cycle periods, the fuel burnup levels, the generated power densities in the core, and the thermal/fast neutron fluxes in irradiation channels are calculated with the computer codes MCU-REA and MCNP-4/B. Results of steady-state thermal-hydraulics results performed with the code ASTRA are also presented. The results show that for all the LEU options analyzed the performance of the reactor is improved when compared with the present HEU core.

## Introduction

The WWR-K reactor presently uses 36% enriched fuel assemblies (FA) with $UAl_x$ alloy and $UO_2$–Al ceramics.

This work presents the results of the analysis of the neutron and physical characteristics of the WWR-K reactor core loaded with LEU FA composed of tubular thin-walled fuel elements (FE) using $UO_2$–Al fuel meat, having the mass density equal to 2.8 g/cm$^3$. Several core configurations, with water and with beryllium reflector, are analyzed. Flux performance, burnup level, burnup cycle lengths, and steady state thermal-hydraulics are examined for these cores. The results show that the selected LEU FA combined with the core configurations used make the converted LEU core better than the present HEU core.

## 1. New Fuel Assembly

Two types of LEU FA (see Figure 1) have been used in this study: the FA-1, composed of eight fuel elements, and FA-2, composed of four fuel elements (FE). The CPS control rods are placed inside FA-2. If required, FA-2 can also be used to locate small-diameter irradiation channels. The FE and FA characteristics are given in Tables 1 and 2. For comparison, figure 2 shows the views of the present HEU FAs.

[1] Work performed with the financial support from "Nuclear Threat Initiative – NTI", USA.

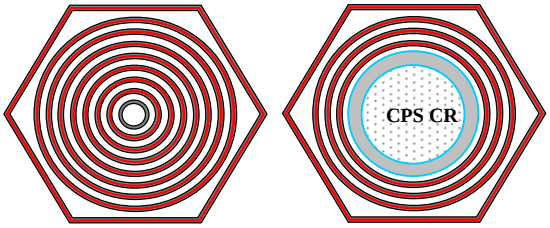



Figure 1 The VVR-KN-type eight-tube FA-1 and four-tube FA-2

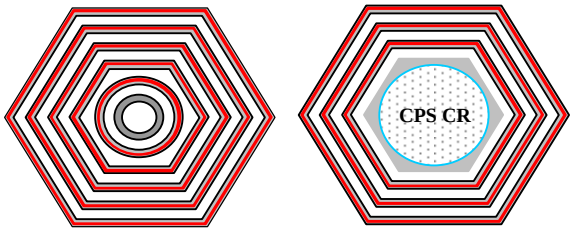



Figure 2 the VVR-C-type five-tube FA-1 and three-tube FA-2

Table 1 Parameters for the VVR-KN eight/four-tube FA

| FA-1 | | | | FA-2 | | |
|---|---|---|---|---|---|---|
| Structural element | Diameter, mm | Thickness, mm | U-235 mass, g per FE | Structural element | Diameter, mm | Thickness, mm |
| FE-1 | 66.3* | 1.6 | 51.92 | FE-1 | 66.3 | 1.6 |
| FE-2 | 59.1 | 1.6 | 41.85 | FE-2 | 59.1 | 1.6 |
| FE-3 | 51.9 | 1.6 | 36.61 | FE-3 | 51.9 | 1.6 |
| FE-4 | 44.7 | 1.6 | 31.37 | FE-4 | 44.7 | 1.6 |
| FE-5 | 37.5 | 1.6 | 26.13 | rod channel | 38.1-35.6 ** | 1.25 |
| FE-6 | 30.3 | 1.6 | 20.89 | control rod clad | 33.6-31.6 *** | 1.0 |
| FE-7 | 23.1 | 1.6 | 15.65 | control rod | 31.6 | |
| FE-8 | 15.9 | 1.6 | 10.41 | | | |
| Struct. tube | 8.8 | 1.0 | _– | | | |

* Face-to-face size of the outer hexagonal FE.
** Control rod channel outer and inner diameters
*** Control rod clad outer and inner diameters

Table 2 Characteristics of the VVR-KN and VVR-TS FA

| Parameter | VVR-KN 8-tube FA | VVR-Ts 5-tube FA |
|---|---|---|
| $U^{235}$ Enrichment | 19.7% | 36% |
| $U^{235}$, g in FA-1 / FA-2 | 234.8 / 161.7 | 112.0 / 83.6 |
| FA-1 heat removal surface area, $cm^2$ | 12163.2 | 8664.2 |
| FE/clad/fuel thickness, mm | 1.6 / 0.45 / 0.7 | 2.3 / 0.7 / 0.9 |
| Inter-FE water gap, mm | 2.0 | 3.0 |
| Meat volume in FA-1/FA-2, $cm^3$ | 425.7 /293.2 | 346.5/261.7 |

## 2. Core Configurations

Two reactor cores are considered: a) with existing arrangement of the CPS control rods (CR) and irradiation channels in the core (version 1, with 18 FA-1 and 10 FA-2; Fig. 3A); and b) with circular layout of irradiation channels and modified arrangement of the CPS CR (version 2, 16 FA-1 and 10 FA-2; Fig.3B). In both cores water and beryllium reflector options are analyzed. For the cores with water reflector, as the fuel is burned the core size needs to be increased and the final (equilibrium size) core contains 33 FA-1 and 10 FA-2 for the Version-1 core, and 30 FA-1 and 10 FA-2 for the Version-2 core (see Figs. 4 and 5). With beryllium reflector the intermediate cores are shown in Figures 6 and 7, and the final cores in figures 7 and 8. The number of FA in each core is defined by the requirement to achieve ~50% maximum average burnup in FA.

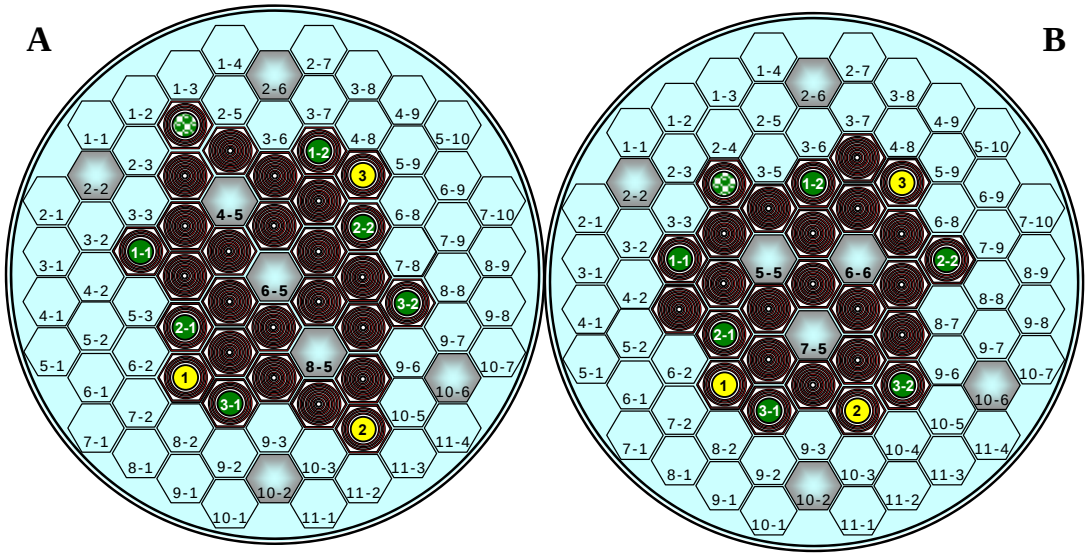



Figure 3 Two versions of the fresh core: (A) core «18+10» and (B) “16+10” ( water reflector)

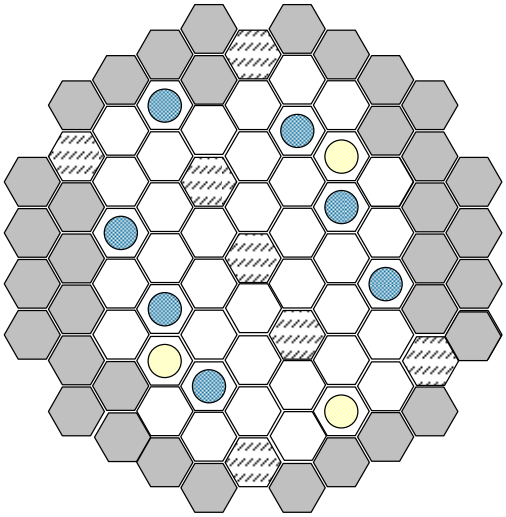


Fig. 4. Version-1 final core «33+10»

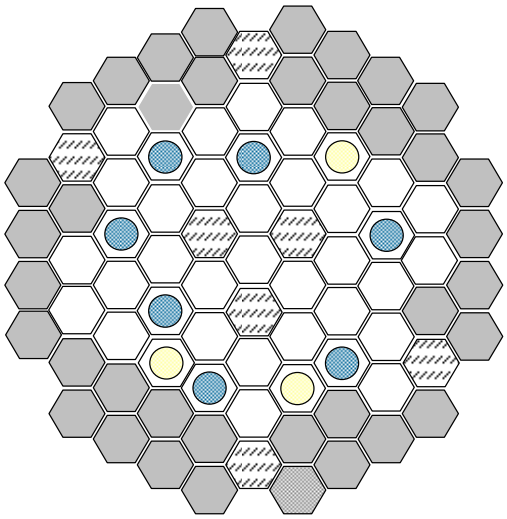


Fig. 5 Version-2 final core «30+10»

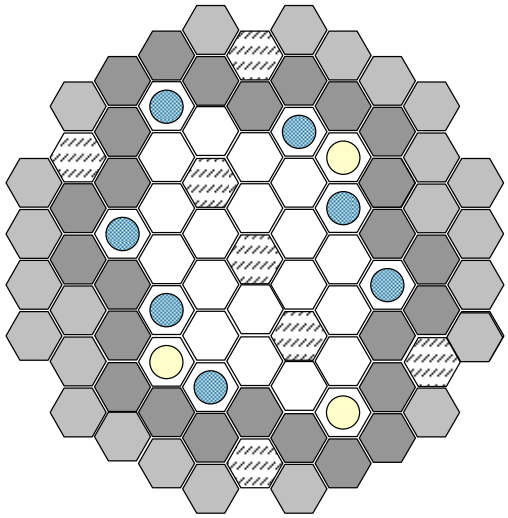


Fig. 6. Version-1 Core with 26 beryllium pieces

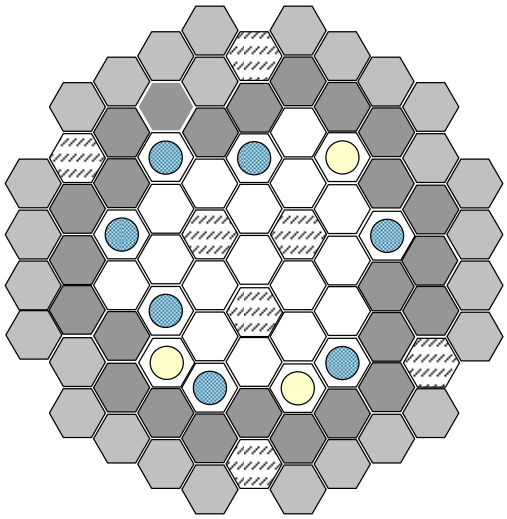


Fig. 7. Version-1 Core with 24 beryllium pieces

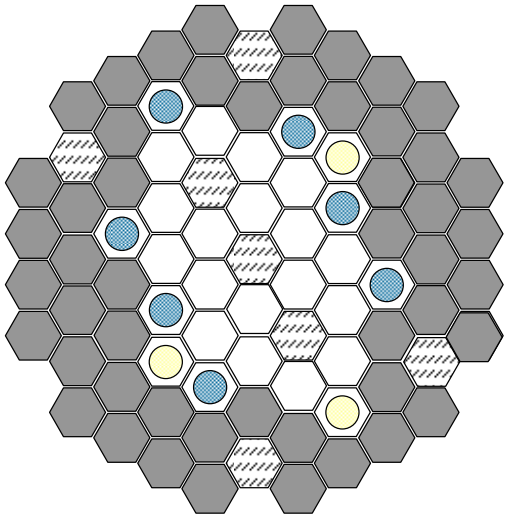


Fig. 8. Version-1 Core with 50 beryllium pieces

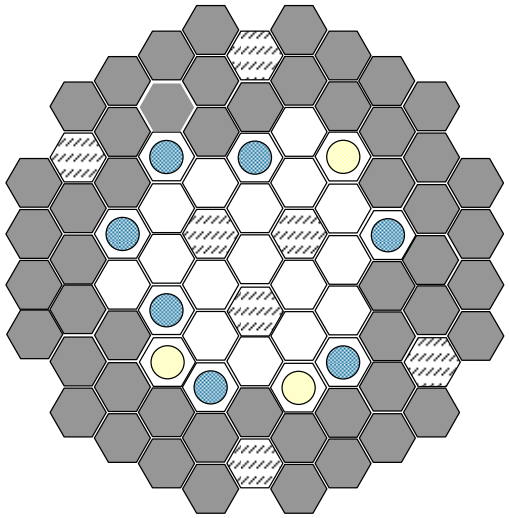


Fig. 9. Version-2 Core with 52 beryllium pieces

## 3. Results

For the fresh core versions 1 and 2 the calculated values of $k_{eff}$ are, respectively: 1.0873±0.0002 ($\rho_{core}$ =8.0 %Δk/k) and 1.0712±0.0002 ($\rho_{core}$=6.6%Δk/κ). The estimated reactivity worth of the CPS control rods is presented in table 3. The shutdown margin of at least 1% subcriticality is safely met for both configurations.

Table 3 the CPS CR Efficiency

| CPS CR inserted | Worth, %(Δk/k) | |
|---|---|---|
| | «16+10» | «18+10» |
| All KO (shim) and AP (regulating) | 10.6 | 8.8 |
| All AZ (safety) | 3.3 | 2.4 |
| Shutdown Margin, % | -2.6 | -1.7 |

In Tables 4 and 5 peak values of the generated power and the average burnup level per FA are given for the cores with water reflector. For both core versions, stationary poisoning by xenon

comprises 3.2 %Δk/k and the reactivity loss due to burnup is, on average, 0.04 %Δk/k per day. For the Version-1/Version-2 cores, the reactor operating cycle period lasts 415/345 days – up to achieving the burnup level, averaged over all assemblies, of ~ 49 %. The reactivity trace for each of the cycles is shown in Figures 10 and 11.

Table 4 Peak Burnup and Generated Power in the Core «18+10»+X FA (with water reflector)

| Cell | Burnup, % | P, kW | Burnup, % | P, kW | Burnup, % | P, kW | Burnup, % | P, kW |
|---|---|---|---|---|---|---|---|---|
| | «18+10» | | «24+10» | | «30+10» | | «33+10» | |
| 5-5 | 15.7 | 302.0 | 34.2 | 253.5 | 44.1 | 210.3 | 49.8 | 182.0 |
| 5-6 | 15.3 | 301.8 | 33.8 | 249.6 | 44.1 | 211.3 | 49.8 | 187.5 |
| 7-5 | 15.6 | 301.8 | 34.1 | 249.6 | 44.5 | 208.3 | 50.2 | 195.5 |
| 7-6 | 15.2 | 298.3 | 34.2 | 252.4 | 44.3 | 209.9 | 50.0 | 192.0 |
| ρ (BOC), % | 7.9 | | 8.1 | | 6.5 | | 4.7 | |
| ρ (EOC), % | 0.22 | | 0 | | 0.42 | | 0.11 | |
| Cycle Length, days | 100 | | 150 | | 100 | | 65 | |

Table 5 Peak Burnup and Generated Power in the Evolving Core "16+10+X FA" (with water reflector)

| Cell | Burnup, % | P, kW | Burnup, % | P, kW | Burnup, % | P, kW |
|---|---|---|---|---|---|---|
| | «16+10» | | «22+10» | | «30+10» | |
| 6-5 | 7.6 | 369.1 | 31.2 | 307.0 | 48.7 | 238.6 |
| ρ (BOC), % | 6.5 | | 8.22 | | 7.88 | |
| ρ (EOC), % | 0.79 | | 0.44 | | 0.0 | |
| Cycle Length, days | 40 | | 150 | | 155 | |

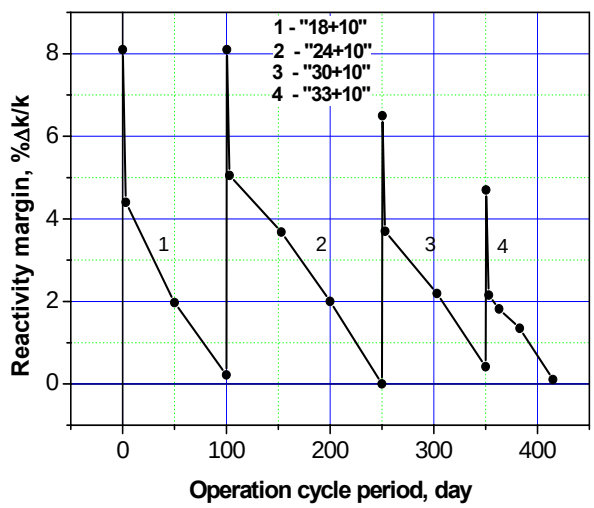



Figure 10 Reactivity Versus Operation Cycle for Version-1 Core (with water reflector)

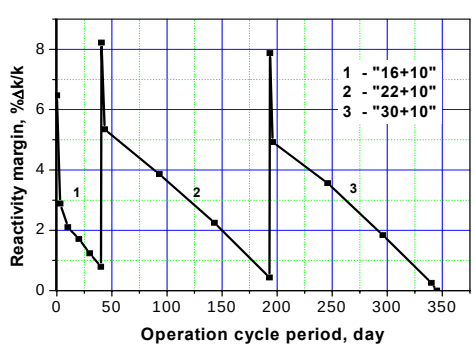



Figure 11 Reactivity Versus Operation Cycle for Version-2 Core (with water reflector)

Table 6 Peak Average FA Burnup and Generated Power Density in the Core with “(18+10) FA+ X Be”

| Cell | Burnup,% | P, kW | P, kW/cm$^3$ | Burnup,% | P, kW | Burnup,% | P, kW | P, kW/cm$^3$ |
|---|---|---|---|---|---|---|---|---|
| | 18+10 | | | 18+10+26Be | | 18+10+50Be* | | |
| **6–3 KO2-1** | **16.0** | 205.4 | **0.1375** | **45.6** | **196.2** | **52.55** | **191.2** | **0.1299** |
| **6–7 KO2-2** | **16.1** | 202.3 | **0.1354** | **45.6** | **196.8** | **52.66** | **187.4** | **0.1273** |
| 8–3 KO3-1 | 13.9 | 173.6 | 0.1162 | 42.2 | 180.4 | **48.67** | **186.6** | **0.1268** |
| 8–7 KO3-2 | 14.1 | 176.7 | 0.1183 | 43.0 | 190.6 | **49.81** | **191.8** | **0.1303** |
| 7–3 AZ1 | 13.4 | 169.5 | 0.1135 | 41.4 | 181.2 | **48.67** | **190.5** | **0.1294** |
| 5– 8 AZ3 | 13.4 | 167.9 | 0.1124 | 41.4 | 182.9 | **48.67** | **189.0** | **0.1284** |
| 5-5 | **15.7** | **302.0** | **0.1303** | **42.2** | 274.3 | **48.14** | **253.3** | 0.1109 |
| 5-6 | **15.3** | **301.8** | **0.1302** | **42.2** | 268.3 | **48.10** | **254.2** | 0.1113 |
| 6-4 | 14.1 | 275.1 | 0.1187 | 38.8 | 251.9 | **44.71** | **240.1** | 0.1051 |
| 6-6 | 14.1 | 271.7 | 0.1172 | 38.8 | 251.4 | **44.79** | **242.3** | 0.1061 |
| 7-5 | **15.6** | **301.8** | 0.1302 | **42.2** | 272.2 | **48.29** | 255.6 | 0.1119 |
| 7-6 | **15.2** | **298.3** | **0.1287** | **42.2** | 275.4 | **48.29** | 248.7 | 0.1089 |
| ρ (BOC/EOC), % | 7.87 / 0.22 | | | 12.16 / 0.99 | | 5.6 / 0.01 | | |
| Cycle Length, d | 100 | | | 200 | | 50 | | |

*24 beryllium pieces are added to the burnt core «18+10»+26Be

Table 7 Peak Burnup and Generated Power Density in the Core with “16+10+52BeBe”

| Cell | Burnup,% | P, kW | P, kW/cm$^3$ | Burnup,% | P, kW | Burnup,% | P, kW | P, kW/cm$^3$ |
|---|---|---|---|---|---|---|---|---|
| | «16+10» | | | “16+10+24Be” | | “16+10+52Be” | | |
| 3- 4 AP | **6.0** | 183.7 | **0.1362** | 40.3 | 200.5 | **48.3** | 196.8 | **0.1468** |
| 6-3 KO2-1 | **6.7** | 206.2 | **0.1359** | 42.3 | 200.0 | **49.7** | 187.2 | **0.1396** |
| 7-8 KO2-2 | 5.9 | 182.8 | **0.1356** | 40.1 | 199.6 | **48.7** | 209.3 | **0.1561** |
| 8-3 KO3-1 | **6.1** | 189.0 | **0.1333** | 40.2 | 196.2 | **48.1** | 186.5 | **0.1391** |
| 9-5 KO3-2 | 5.7 | 175.0 | 0.128 | 39.7 | 188.4 | **47.3** | 185.4 | **0.1383** |
| 7-3 AZ1 | **6.5** | 193.6 | **0.1345** | 41.5 | 198.0 | **49.4** | 196.4 | **0.1465** |
| 5-8AZ3 | 5.7 | 170.2 | **0.1309** | 38.2 | 192.7 | **46.5** | 199.9 | **0.1491** |
| 9-4 AZ2 | **6.1** | 181.8 | **0.131** | 39.8 | 192.8 | **47.5** | 188.2 | **0.1404** |
| 6-4 | **6.8** | **324.6** | **0.1421** | 39.6 | 236.2 | **46.8** | **265.2** | 0.1275 |
| 6-5 | **7.6** | **369.1** | **0.1616** | **43.7** | 287.1 | **51.3** | **292.3** | **0.1405** |
| ρ (BOC/EOC), % | 6.5 / 0.79 | | | 13.2 / 0.08 | | 5.6 / 0.01 | | |
| Cycle Length, d | 40 | | | 225 | | 50 | | |

* 28 beryllium pieces are added to the burnt core «16+10»+24Be

Table 8 Peak Burnup and Generated Power Density in the Core with “16+10+2 +24Be”

| Cell | Burnup, % | P, kW | Burnup, % | P, kW | Burnup, % | P, kW | Burnup, % | P, kW | Burnup, % | P, kW |
|---|---|---|---|---|---|---|---|---|---|---|
| | «16+10» | | «16+10+10Be» | | “16+10+17Be” | | “16+10+24Be” | | “16+10+2+24Be” | |
| 3 - 4 AP | **6.0** | 183.7 | 25.9 | 190.0 | 29.7 | 203.2 | 39.9 | 191.7 | 45.6 | 174.0 |
| 6 - 3 KO21 | **6.7** | 206.2 | 24.3 | 181.1 | 33.5 | 184.1 | 40.3 | 195.4 | 45. | 173.8 |
| 7 - 8 KO22 | 5.9 | 182.8 | 25.9 | 191.4 | 31.9 | 178.2 | 38.4 | 197.9 | 44.1 | 175.8 |
| 8 - 3 KO31 | **6.1** | 189.0 | 26.6 | 192.9 | 31.9 | 179.6 | 38.4 | 190.2 | 43.7 | 165.7 |
| 9 - 5 KO32 | 5.7 | 175.0 | 25.1 | 185.5 | 33.8 | 190.0 | 39.9 | 179.8 | 45.2 | 168.3 |
| 7 - 3 AZ1 | **6.5** | 193.6 | 25.1 | 187.0 | 31.9 | 174.5 | 38.8 | 192.5 | 43.7 | 168.3 |
| 5 - 8AZ3 | 5.7 | 170.2 | 26.2 | 203.9 | 30.7 | 181.1 | 37.3 | 187.2 | 42.6 | 179.8 |
| 9 - 4 AZ2 | **6.1** | 181.8 | 25.1 | 182.6 | 34.1 | 191.4 | 40.3 | 184.7 | 45.2 | 164.8 |
| 6 - 4 | **6.8** | **324.6** | 27.0 | 306.1 | 33.8 | 286.9 | 40.3 | 281.4 | 45.2 | 259.5 |
| 6 - 5 | **7.6** | **369.1** | 30.4 | 347.2 | 35.7 | 323.0 | 45.2 | 309.0 | 50.6 | 283.7 |
| $\rho_{BOC}/\rho_{EOC}$, % | 6.5 / 0.79 | | 7,93 / 0.17 | | 5.4 / 0.25 | | 5.8/0.34 | | 5.3/0.1 | |
| Cycle Length, d | 40 | | 120 | | 50 | | 45 | | 40 | |

For the Version-1/Version-2 cores with beryllium reflector, tables 6 and 7 show the peak values of the generated power in both core versions for the case when beryllium blocks are added simultaneously. In reality, the beryllium reflector is set up gradually, as fuel burns up, as determined by control rod worth (see, e.g., figure 14, where instead of the second ring of beryllium, two FAs are added at the last, fifth cycle – to achieve 50-% burnup and to save beryllium). Figure 14 and Table 8 correspond to the alternative evolving core “(16FA1+10FA2)+10Be+7 Be+7Be+2FA” with achieved 50-% burnup). For Version-1/Version-

2 cores, the calculated operation cycle period comprises 350/315 days – up to achieving 48 to 51 % of burnup. The reactivity trace for each of the cycles is shown in Figures 12 and 13.

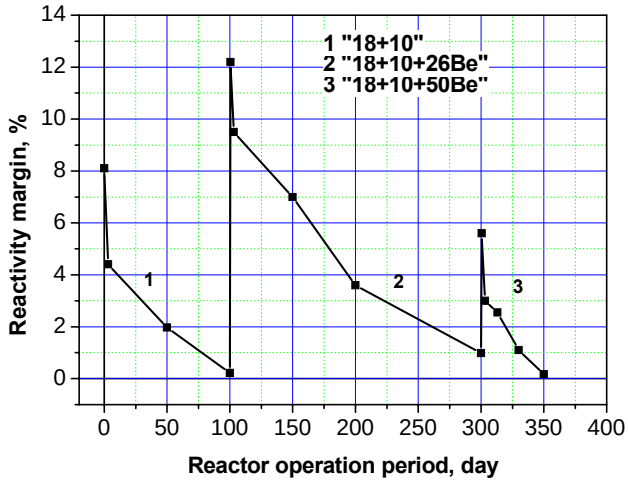



Figure 12 Reactivity versus Operation Cycles for Version-1 Core (with beryllium reflector)

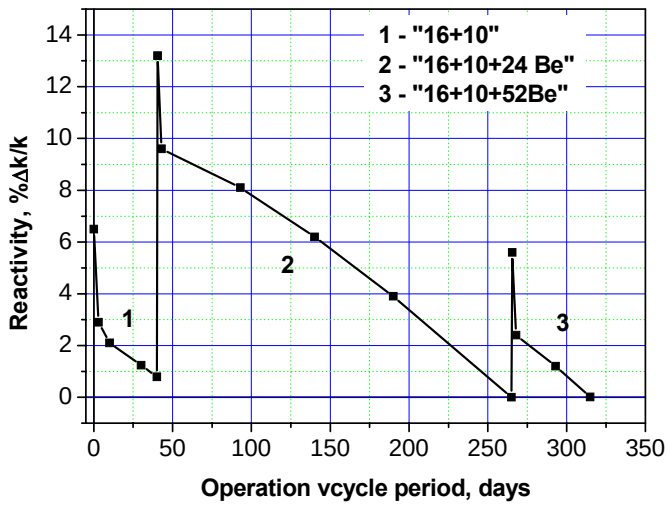



Figure 13 Reactivity versus Operation Cycles for Version-2 Core (with beryllium reflector)

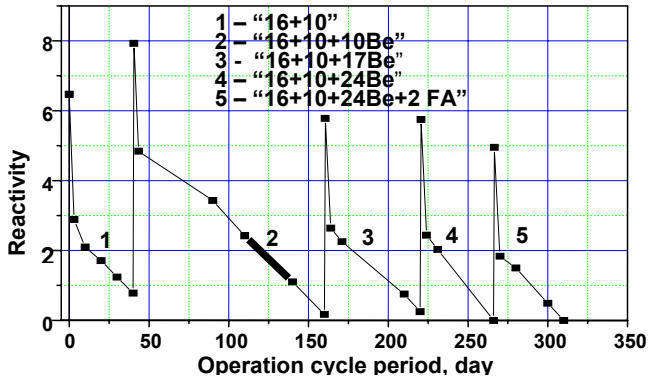



Figure 14. Reactivity versus Operation Cycles for Version-2 Core (with beryllium reflector) – Evolving Core load "16+12+24Be)

Results for the beginning of cycle fluxes at the irradiation positions are presented in Tables 9 and 10 below. These results show that for the cores with water reflector (results in the first five columns of table 9 and first three columns of table 10) the increase in the core volume (as more FA are loaded) causes a decrease in the neutron flux in the irradiation channels located inside the core (cell3 6-5, 4-5, and 8-5) but increases in the reflector channels. This increase is related to the proximity of the added FA to the irradiation positions. With beryllium reflector (see last two columns in tables 9 and 10) the neutron thermal flux in the peripheral channels increases noticeably, reaching $0.9 \cdot 10^{14}$ to $1.0 \cdot 10^{14}$ $cm^{-2}s^{-1}$.

It is important to note that for all cores analyzed in this study the flux performance for the LEU cores is better than the performance obtained with the present HEU core. It is also clear that the addition of the beryllium reflector improves the performance even more when compared with the water reflector.

Table 9 - BOC Flux Performance for the Cores with "(18+10+X) FA" and "(18+10) FA + X Be"
(Uncertainties in the thermal/fast neutron flux: ≈ 1% / 5 %)

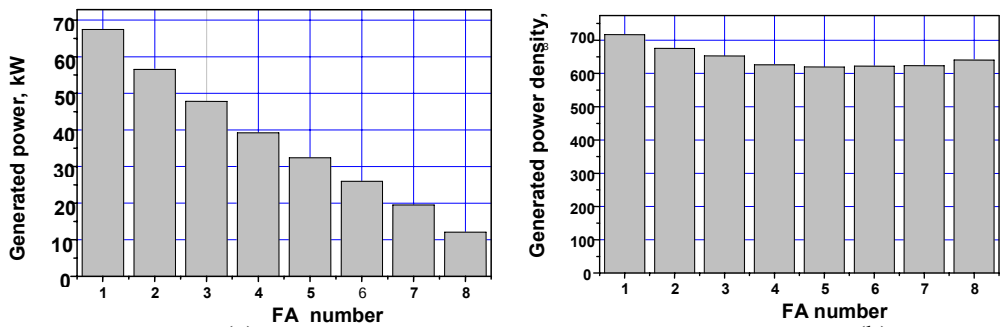
| code | "18+10" | | "30+10" BOC | "30+10" EOC | "33+10" | "18+10+26Be" | "18+10+50Be" |
|---|---|---|---|---|---|---|---|
| | MCU-REA | MCNP/4B | MCU-REA | | | | |
| ρ, % | 8.0 | 7.1 | 6.7 | 3.4 | 5.1 | 12.2 | 5.9 |
| Cell | Thermal/ Fast Neutron Flux ($E_n \leq 0.4$ eV / $E_n \geq 1.15$ MeV) | | | | | | |
| 6-5 | 2.3e+14/ 4.2e+13 | 2.4e+14/ 4.6e+13 | 1.9e+14/ 3.3e+13 | 1.8e+14/ 3.0e+13 | 1.7e+14/ 2.7e+13 | 2.2e+14/ 3.7e+13 | 2.3e+14/ 4.0e+13 |
| 8-5 | 1.8e+14/ 3.4e+13 | 1.8e+14/ 3.6e+13 | 1.5e+14/ 2.5e+13 | 1.5e+14/ 2.4e+13 | 1.6e+14/ 2.4e+13 | 1.9e+14/ 3.4e+13 | 2.0e+14/ 3.3e+13 |
| 4-5 | 1.9e+14/ 3.7e+13 | 1.8e+14/ 3.5e+13 | 1.5e+14/ 2.6e+13 | 1.6e+14/ 2.9e+13 | 1.5e+14/ 2.4e+13 | 1.9e+14/ 3.4e+13 | 2.1e+14/ 3.2e+13 |
| 2-2 | 5.2e+13/ 4.4e+12 | 5.6e+13/ 4.3e+12 | 5.7e+13/ 5.6e+12 | 5.7e+13/ 6.6e+12 | 5.3e+13/ 6.6e+12 | 7.5e+13/ 4.1e+13 | 9.6e+13/ 4.6e+12 |
| 2-6 | 5.7e+13/ 5.0e+12 | 5.7e+13/ 4.0e+12 | 6.1e+13/ 6.1e+12 | 6.1e+13/ 6.6e+12 | 6.1e+13/ 6.8e+12 | 7.7e+13/ 4.0e+13 | 9.6e+13/ 4.2e+12 |
| 10-2 | 5.6e+13/ 4.6e+12 | 5.9e+13/ 4.1e+12 | 6.3e+13/ 6.3e+12 | 6.2e+13/ 6.1e+12 | 7.6e+13/ 1.1e+13 | 7.8e+13/ 4.0e+13 | 9.8e+13/ 5.2e+12 |
| 10-6 | 5.3e+13/ 4.1e+12 | 5.6e+13/ 4.0e+12 | 5.7e+13/ 6.3e+12 | 6.0e+13/ 6.1e+12 | 5.9e+13/ 7.4e+12 | 7.9e+13/ 3.9e+13 | 9.3e+13/ 4.4e+12 |

Table 10 Neutron flux density values for the core (16+10+X) FA and (16+10) FA + X Be
(Uncertainties in the thermal/fast neutron flux: ≈ 1% / 5 %)

| Version | 16+10 MCU-REA | 16+10 MCNP/4B | 30+10 MCU-REA | 16+10+24BE MCU-REA | 16+10+52BE MCU-REA |
|---|---|---|---|---|---|
| ρ (BOC), % | 6.6 | 5.9 | 7.9 | 12.9 | 5.8 |
| Cell | Thermal/Fast Neutron Flux ($E_n \leq 0.4$ eV / $E_n \geq 1.15$ MeV) | | | | |
| 5 - 5 | 2.2e+14/4.0e+13 | 2.2e+14/4.4e+13 | 1.7e+14/2.9e+13 | 2.2e+14/3.7e+13 | 2.3e+14/3.6e+13 |
| 6- 6 | 2.1e+14/3.5e+13 | 2.2e+14/4.3e+13 | 1.7e+14/2.9e+13 | 2.2e+14/3.8e+13 | 2.3e+14/3.8e+13 |
| 7- 5 | 2.2e+14/4.1e+13 | 2.3e+14/4.5e+13 | 1.8e+14/2.9e+13 | 2.2e+14/4.0e+13 | 2.3e+14/3.8e+13 |
| 2- 2 | 5.1e+13/3.4e+12 | 5.6e+13/4.4e+12 | 5.7e+13/7.6e+12 | 7.2e+13/3.4e+12 | 9.3e+13/3.5e+12 |
| 2- 6 | 4.4e+13/2.4e+12 | 5.7e+13/4.4e+12 | 6.1e+13/5.1e+12 | 6.2e+13/2.4e+12 | 9.2e+13/2.9e+12 |
| 10- 2 | 5.3e+13/3.6e+12 | 5.9e+13/4.4e +12 | 5.1e+13/5.0e+12 | 7.7e+13/4.0e+12 | 9.3e+13/3.0e+12 |
| 10- 6 | 4.7e+13/2.5e+12 | 5.6e+13/4.6e +12 | 6.2e+13/6.6e+12 | 6.2e+13/3.3e+12 | 9.0e+13/3.0e+12 |

Finally, steady-state thermal-hydraulics calculations have been performed for the hottest FA, which is located in cell 6-5 (Version-2 Core). The FA hottest face is adjacent to cell 7-5 ("wet" channel - see Fig. 3B). In figure 15 distributions of the generated power and power density over eight fuel elements for the hottest FA are shown. For the hottest (outer, hexagonal) FE, the calculated peak is 1.40. For these calculations, several possible coolant pressure drops in the core

are used: 1.5, 2.0 and 3.0 m of water column, corresponding to coolant velocity in inter-FE water gaps equal to 1.86, 2.15 and 2.64 m/s. An inlet coolant temperature equal to 35 $^{o}$C, coolant pressure in the FA inlet of 1.35 bar, clad/fuel thermal conductivities equal to 0.17 kW/m/$^{o}$C / 0.08 kW/m/$^{o}$C were used. The results of these calculations are shown in Table 11, where it can be seen that even for the lowest coolant velocity of 1.86 m/s (corresponding to a 0.15 m of water pressure drop) the minimum ratio of margin to ONB is equal to 1.47; this ratio is larger than the normally accepted value of 1.4.




(a) (b)

Figure 15 Generated power (a) and generated power density (б) in fuel elements of the 8-tube FA

Table 11 Results of Steady-State thermal calculation (Version-2 Core, water reflector)

| Parameter | Pressure drop, bar | | |
|---|---|---|---|
| | 0.15 | 0.20 | 0.30 |
| Reactor power rating, MW | 6 | 6 | 6 |
| Maximum generated power density in the FE meat, W/cm$^3$ | 1834 | 1834 | 1834 |
| Water temperature at the core inlet, °C | 35 | 35 | 35 |
| Max thermal flux (from the FE outer/inner surface), kW/m$^2$ | 678/604 | 676/606 | 674/609 |
| Max temperature at the FE surface, °C | 96 | 90 | 82 |
| The ONB temperature on FE surface (by Forster-Greif), °C | 125 | 124 | 123 |
| Minimum ONB margin | 1.47 | 1.63 | 1.87 |

## 4. Conclusions

The results of the analyses performed in this study lead to the following conclusions:

- The feasibility study that has been carried out substantiates the choice of the LEU FA $UO_2$–Al FA with fuel meat density equal to 2.8 g/cm$^3$ for the conversion of the WWR-K reactor. This fuel meat density has been reliably manufactured, and irradiation tests have been performed for a different FA geometry.
- For two fresh core versions considered, (A) with existing arrangement of CPS control rod channels and irradiation channels, and (B) with more compact arrangement of CPS CR channels and circular arrangement of central irradiation channels, the thermal neutron flux in the core irradiation channels reached 1.9 to 2.3 $10^{14}$ cm$^{-2}$s$^{-1}$ at the reactor power rating 6 MW, being almost two times higher than in the existing HEU core.
- Due to presence of the side beryllium reflector, the thermal neutron flux in the peripheral irradiation channels increases to 0.9 to 1.0 $10^{14}$ cm$^{-2}$s$^{-1}$. The beryllium reflector also makes it possible to use large-diameter channels (100, 200 mm) in the reactor vessel.

- Use of this high-density fuel meat (2.8 g/cm$^3$) FA and side beryllium reflector makes the core economical indices substantially better – the FA average burnup can achieve ~ 50 %, and the net CPS CR worth provides long operation cycles without refueling.
- Steady-state thermal-hydraulics analyses show that the analyzed cores meet the safety criterion for margin to ONB.

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