RERTR 2011 — 33rd INTERNATIONAL MEETING ON
REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS

October 23-27, 2011
Marriott Santiago Hotel
Santiago, Chile

Neutronic Parameters of the IR-8 Reactor Core Consisting of IRT-3M Type FA's with U-9%Mo LEU Fuel Being Analyzed

Y.E. Pesnya, D.Y. Erak, V.A. Nasonov, A.V. Taliev
National Research Centre "Kurchatov Institute"
1, Akademika Kurchatova Sq., 123182 Moscow – Russian Federation

ABSTRACT

As a part of the RERTR program NRC "Kurchatov Institute" with financial support from U.S. Department of Energy studies the feasibility of conversion of the IR-8 reactor from HEU to LEU(19.7%) fuel. At the moment after finishing the calculating analysis of neutronic and thermal-hydraulic characteristics of the reactor with HEU a detailed calculation model with IRT-3M (19.7% enrichment of ^{235}U) FA's was created. By means of calculations using MCU-PTR code the equilibrium cycle length with LEU-fuel was determined. All the necessary calculations for the gradual replacement of HEU to LEU fuel with subsequent output of the IR-8 reactor at the equilibrium cycle mode of partial loads were carried out. Results of neutron calculation analysis parameters of the IR-8 reactor equilibrium cycle with LEU are presented in this report.

1. Introduction

After finishing the calculating analysis of neutronic and thermal-hydraulic characteristics of the IR-8 reactor [1] with HEU NRC "Kurchatov Institute" under the RERTR program began to study the calculated characteristics of the reactor with LEU fuel [2].

For this purpose the detailed full neutronic models of IR-8 reactor from HEU fuel were created to calculations using the program MCU-PTR [3], and the strategy of reactor conversion to LEU fuel by partial reloading was determinated.

2. MCU-PTR code description

MCU-PTR code with the data bank MDBPTR50 [3] is developed for simulation of neutron and photon particles transport by analog and non-analog Monte Carlo methods. The simulation is realized on the basis of the evaluated nuclear data considering depletion process. All necessary characteristics of nuclides being set as burnable in initial data are located in BURN part of the data bank. That contains approximately 1100 nuclides.

The code was verified and validated (V&V) and currently the procedure of certification by Rostehknadzor (Russian regulation body) is carried out.

3. Calculating models of IR-8 reactor loadings for conversion to LEU fuel

The geometry of the calculating model (Figures 1…3) reproduces the actual structure of the core and reflector of the reactor IR-8, including the location in which the experimental vertical and horizontal channels for the analysis occurring in the core and reflector neutron-physical processes. In order to simplify the whole space outside the reactor vessel is filled with water. Reactor tank and biological shield are not counted. This model consists of ~ 16000 registration zones, each characterized by a specific material with a given initial isotopic compositions.
The core is divided to 30 layers on height, each thickness is 2 cm. The fuel in each FA is divided to 180 zones (30×6 fuel elements).

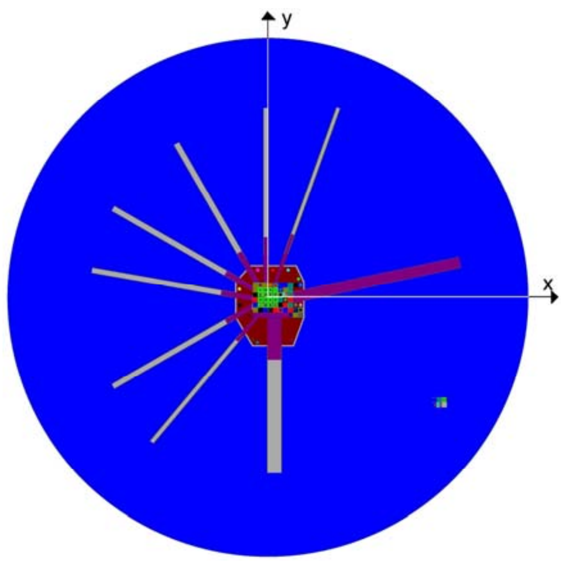


Figure 1. Cross section of calculating model

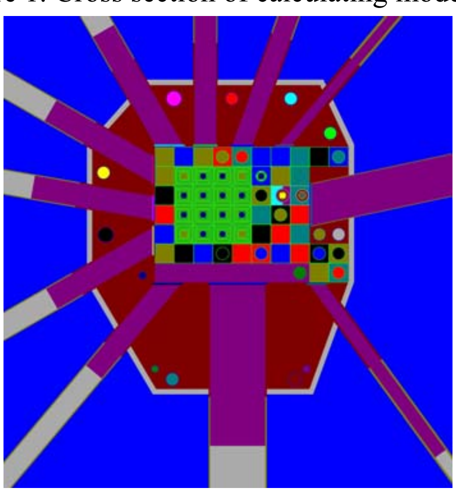


Figure 2. Cross section of reactor with HEC's

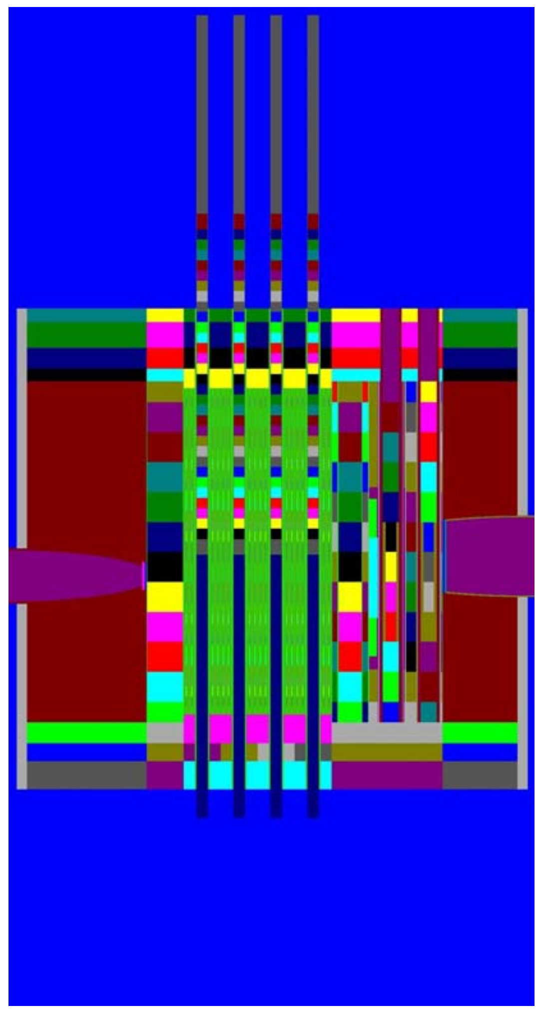


Figure 3. Longitudinal section of reactor calculating model

As a reference time in the reactor operation to determine the parameters of the reactor is selected beginning of the equilibrium cycle of his operation with LEU fuel [2]. As a starting loading for the calculating output of the reactor in the equilibrium cycle the loading # 35 with HEU fuel and with AR's in 6-4 and 7-3 cells is selected. In this loading two IRT-3M fuel assemblies 19.7% enrichment, instead of two "fresh" FA 90% enrichment, are loaded (Figures 4 and 5). On the basis of this variant of loading detailed full-scale neutronic models of IR-8 loadings with HEU and/or LEU fuel have been created.

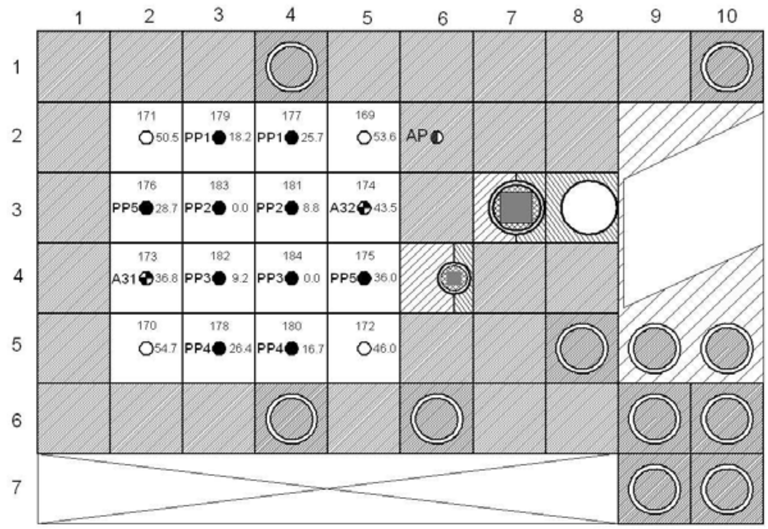


Figure 4. Configuration of the IR-8 loading # 35 (HEU fuel).
Excess reactivity – 8.2 %Δk/k

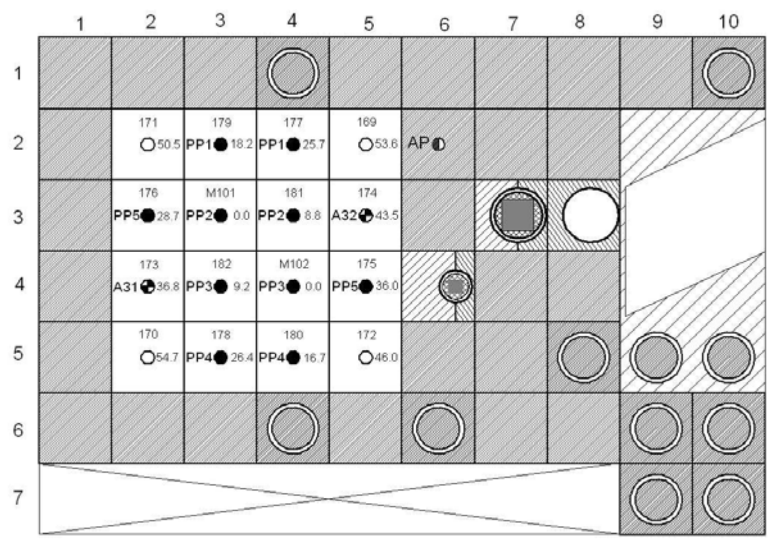


Figure 5. Configuration of IR-8 loading # 1M
(14 FA with HEU and 2 FA with LEU fuel)
Excess reactivity –7.5 %Δk/k

Legend for loading configurations

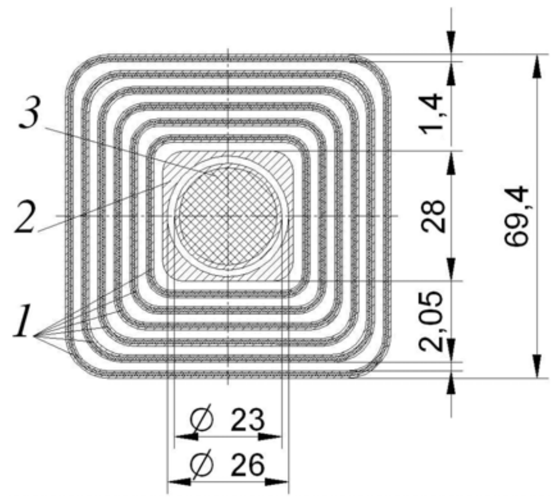
- FA number (HEU/HEU) average burn-up U^{235} in FA, %
- 6-tube FA IRT-3M
- 6-tube FA IRT-3M with shim rod
- 6-tube FA IRT-3M with safety rod
- whole beryllium block
- beryllium block with hole d=48 mm and plug d=44 mm
- beryllium block with automatic regulating rod
- gamma-radiation shield with AR in 6-4 cell
- gamma-radiation shield with AR in 7-3 cell
- gamma-radiation shield for AR in 8-3 cell

3.1 Modeling of IRT-3M FA in the core

The core of IR-8 reactor consists from sixteen fuel assemblies (FA) IRT-3M type with tubular fuel elements square section (Figure 6). The main parameters of fuel elements and FA of IRT-8 are presented in Table 1 [4, 5]. Radii of corner rounding in IRT-3M FA with LEU fuel are larger than in IRT-3M FA with HEU fuel (Figure 7 and 8).
Hydraulic characteristics of FA were experimentally studied [6].
Calculating modeling of IRT-3M FA in the IR-8 core are presented at Figures 7 and 8.

3.2 Modeling of loadings with mixed core consisting of HEU and LEU

For conversion the IR-8 reactor to LEU fuel and output it in the equilibrium cycle the same scheme as for the equilibrium cycle with HEU fuel was used.Geometry changes are only in the core due to differences between the thickness of the meat and corner radii of the IRT-3M FA with LEU and HEU fuel (Figures 7 and 8).

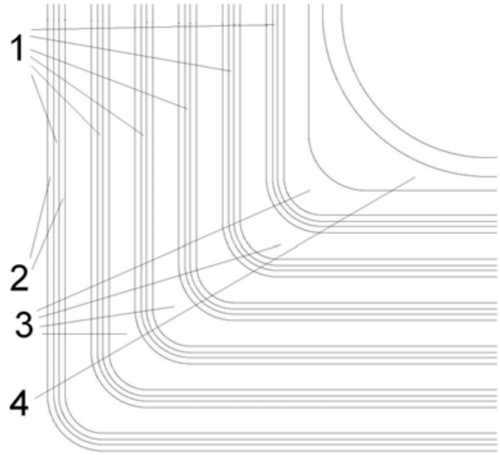


1 – fuel elements;
2 – channel of the CPS rod;
3 – CPS rod

Figure 6. Cross section of IRT-3M FA with control rod

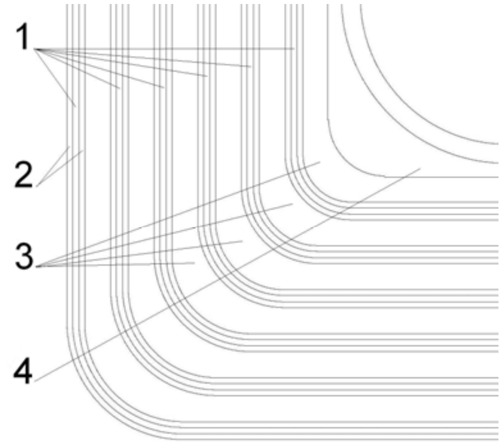
Table 1. The main parameters of fuel elements and IRT-3M FA

FA	IRT-3M	IRT-3M
Fuel enrichment, %	90	19.7
^{235}U content, g	264	352
Fuel meat thickness, mm	0.4	0.5
Active length of meat, mm	600	600
Fuel meat composition	UO_2-Al	U- 9%Mo
Uranium density in the meat, g/cm^3	1.07	5.4
Cladding material	Al alloy CAB-1	Al alloy CAB-1
Cladding thickness, mm	0.5	0.45
Number of fuel elements in FA	6	6
Heat-exchange surface, m^2	1.42	1.38



1 - Meat (UO_2-Al).
2 - FE cladding (Al).
3 - Gaps with water
4 - Channel for the CPS rod

Figure 7. Calculating cross section of IRT-3M FA with HEU fuel



1 - Meat (U- 9%Mo).
2 - FE cladding (Al).
3 - Gaps with water
4 - Channel for the CPS rod

Figure 8. Calculating cross section of IRT-3M FA with LEU fuel

4. Some results of the reactor loading for conversion to LEU fuel calculating analysis

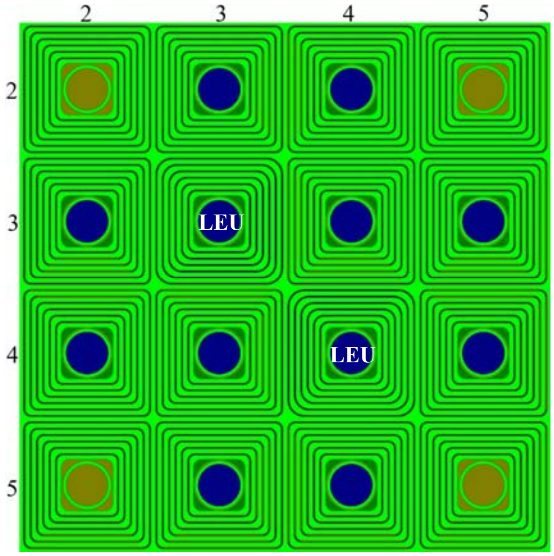
For output the IR-8 reactor in the equilibrium cycle as the start loading # 35 was selected (Figure 4).

4.1 Burnout of ^{10}B in the CPS control rods

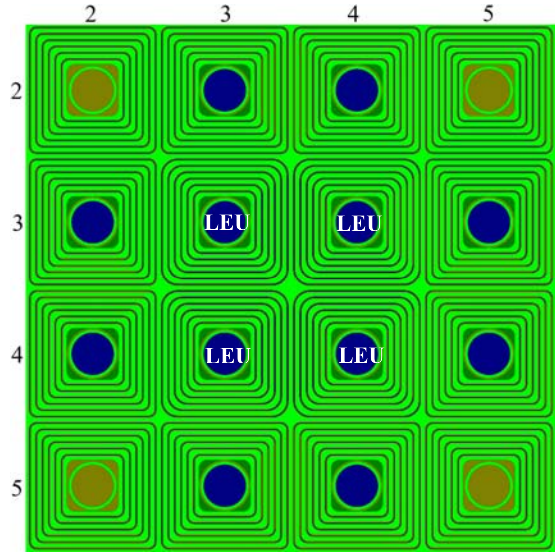
Registration zones with B_4C control rods of loading # 35 with burnt absorber were used to prepare the starting variant # 1M and subsequent calculations by the output of the reactor in the equilibrium cycle. In these calculations nuclide composition of the registration zones with B_4C control rods did not change.

4.2 Conversion to LEU. Changing of excess reactivity

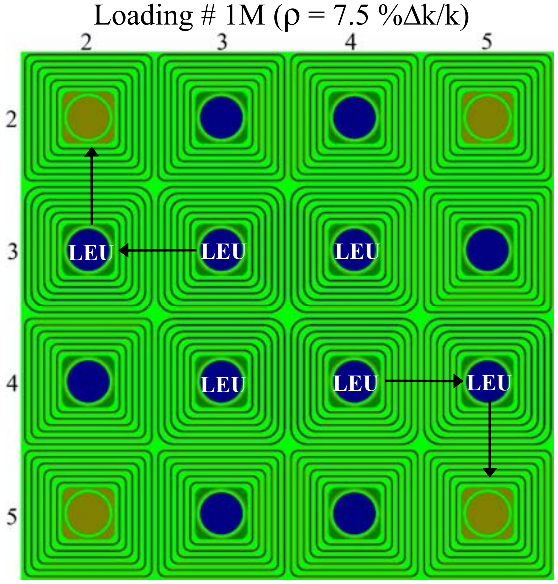
Conversion of the reactor to LEU fuel was carried out in the regime of partial reloadings, in each of them two “fresh” IRT-3M type FA’s with U-9%Mo fuel were loaded into the center of the core. And so at the beginning of the cycle # 8M the IR-8 reactor core consisted of only LEU FA’s. Principal scheme of reloadings and results of calculating determination of excess reactivity values (ρ) for each cycle during replacing the HEU with LEU are presented at Figure 9 (see below).



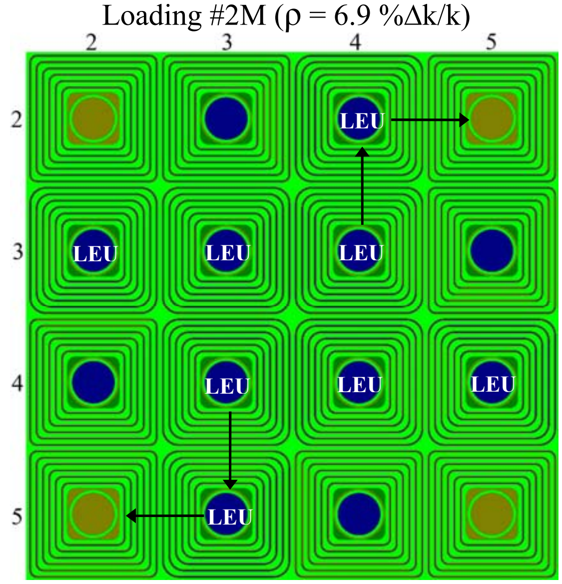
Loading # 1M (ρ = 7.5 %Δk/k)



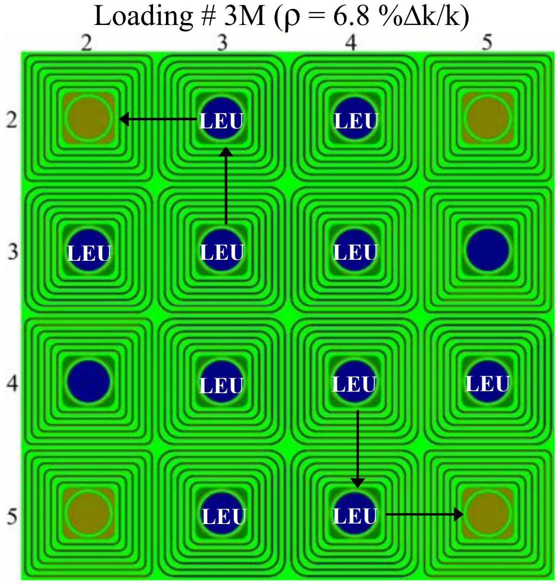
Loading #2M (ρ = 6.9 %Δk/k)

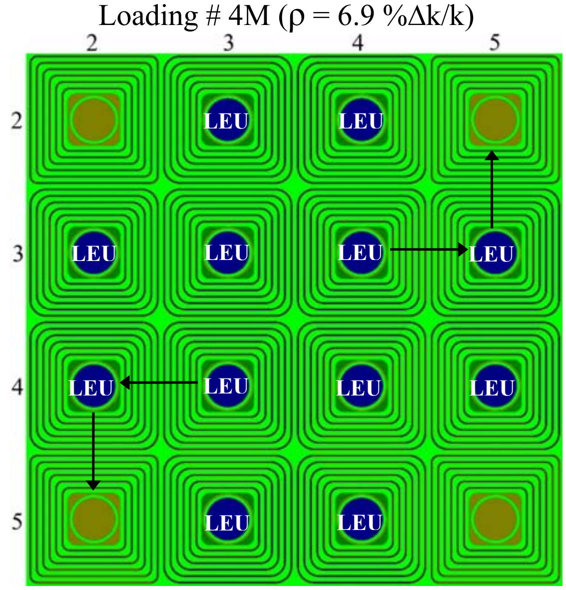


Loading # 3M (ρ = 6.8 %Δk/k)

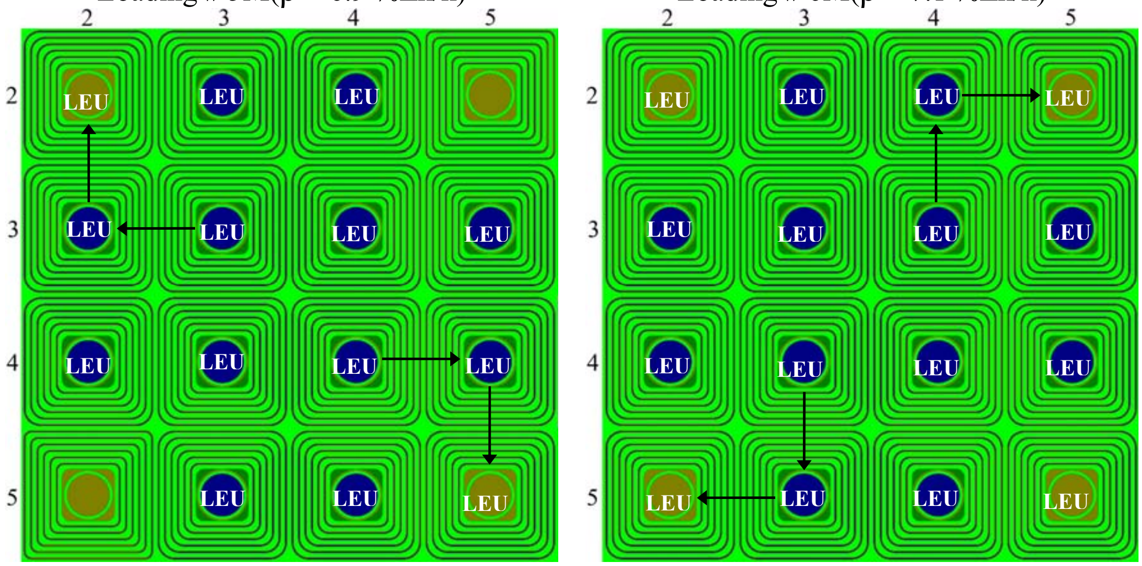


Loading # 4M (ρ = 6.9 %Δk/k)





Loading # 5M(ρ = 6.9 %Δk/k) Loading # 6M(ρ = 7.1 %Δk/k)



Loading # 7M(ρ = 7.4 %Δk/k) Loading # 8M(ρ = 7.8 %Δk/k)

Figure 9. Principal scheme of the IR-8 reactor conversion to LEU fuel.

4.3 Poisoning of the beryllium reflector

In the model of starting loading # 1M (Figure 9) the registration zones of stationary and removable beryllium reflectors have been set as the zone with the possibility of burnout, and changes in isotopic composition due to poisoning. To assess the effect of beryllium poisoning fulfilled comparative calculations, in which the registration area of stationary and removable beryllium reflector filled with "fresh" beryllium. Carried out calculations allowed to determine the change in reactivity due to poisoning of the beryllium reflector, which amounted to 0.8 and 0.84 %Δk/k for loadings # 1M and # 8M respectively.

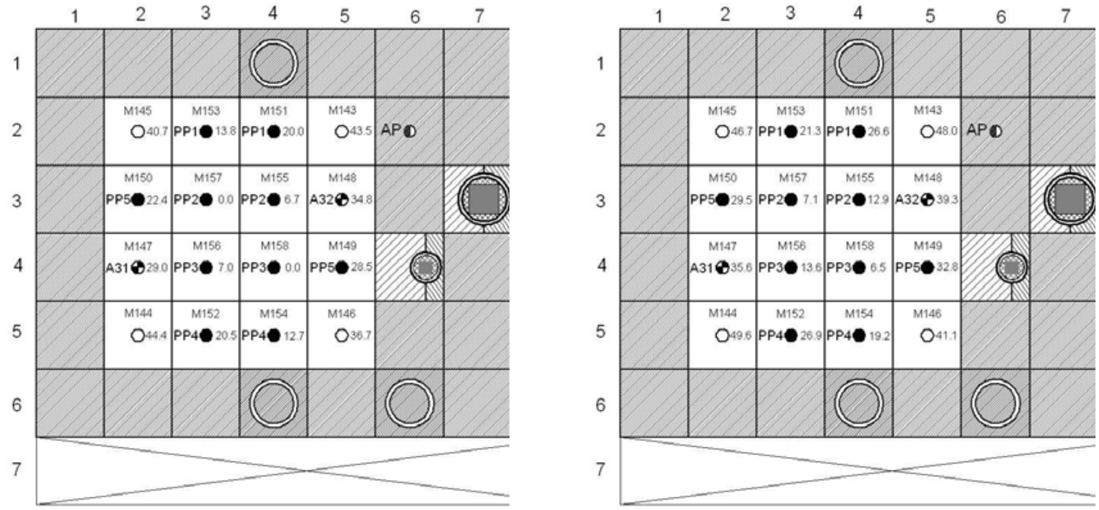
5. Equilibrium cycles of the IR-8 reactor with LEU fuel

Taking the loading # 35 with AR’s in cells 7-3 and 6-4 (Figure 4), the reactor output in the equilibrium cycle in the regime of partial reloads was carried out.

The configuration of the reactor loadings for transient cycles of the output in the equilibrium cycle with AR’s in cells 7-3 and 6-4 are presented in Figures 10 - 14. The ^{235}U burn-up is shown at the beginning and the end of this cycle. The reloading of fuel assemblies is described on top of each picture, which must be fulfilled for the formation of the current load from the previous one. Below each figure indicate the cycle length (full power days – FPD’s) and energy generation for the IR8 reactor (Megawatt days per cycle).

Setting AR in the first row removable beryllium reflector leads to irregularity of the neutron field, which in turn affects the value of burn-up in the FA cells 5-3 and 5-4. Therefore, the output of the reactor at the equilibrium cycle with the AR in cells 6-4 and 7-3 every 4-cycle provides change of places FA’s in cells 5-3 and 2-4, as well as in cells 5-4 and 2-3.

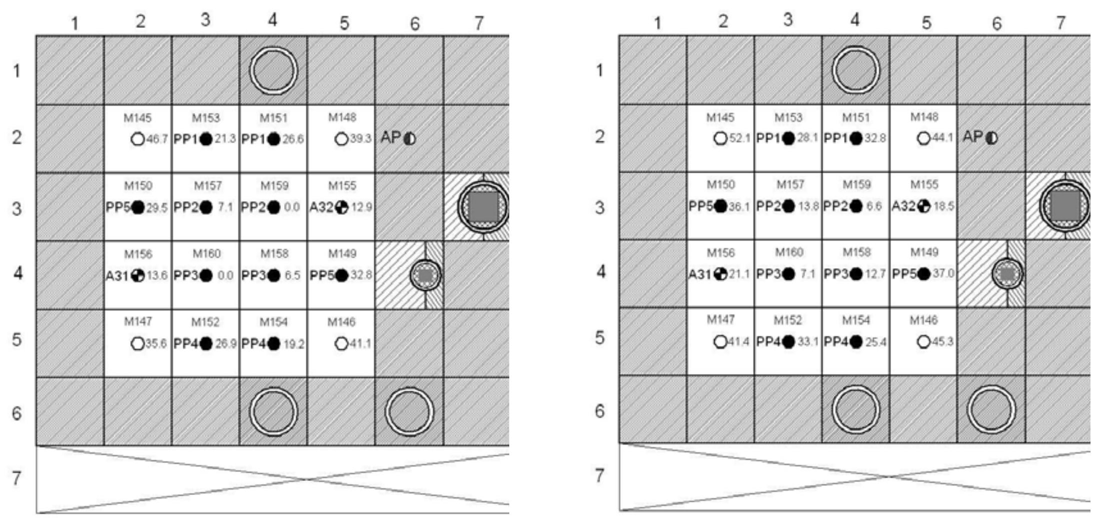
The FA reloading order in the IR-8 core for neutronic calculations of the cycle # 29M:
Loading of fresh FA ➔ 3-3 ➔ 3-2 ➔ 2-2 ➔ ➔ Unloading of FA with burnup 48%
Loading of fresh FA ➔ 4-4 ➔ 4-5 ➔ 5-5 ➔ Unloading of FA with burnup 46%
FAs exchange places: 2-3 ↔ 5-4 и 2-4 ↔ 5-3.



Beginning of cycle (ρ = 7.16 %Δk/k) End of cycle (ρ = 1.83 %Δk/k)

Figure 10. The FA fuel burnup for operating reactor cycle # 29M.
The cycle length – 58 FPD's. Energy generation – 290 MW-days.

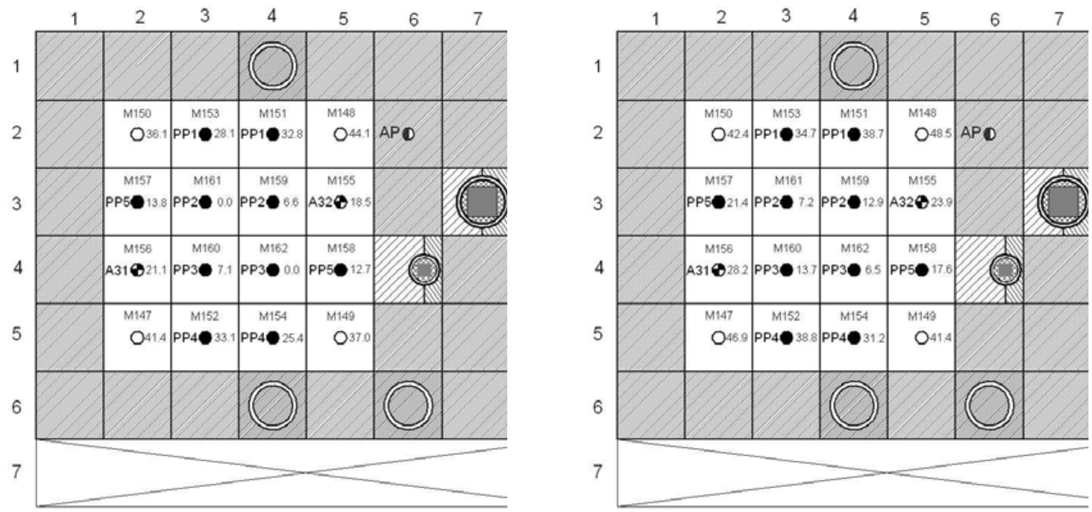
The FA reloading order in the IR-8 core for neutronic calculations of the cycle # 30M:
Loading of fresh FA ➔ 4-3 ➔ 5-3 ➔ 5-2 ➔ Unloading of FA with burnup 48%
Loading of fresh FA ➔ 3-4 ➔ 2-4 ➔ 2-5 ➔ Unloading of FA with burnup 50%



Beginning of cycle (ρ = 7.12 %Δk/k) End of cycle (ρ = 1.85 %Δk/k)

Figure 11. The FA fuel burnup for operating reactor cycle # 30M.
The cycle length – 58 FPD's. Energy generation – 290 MW-days.

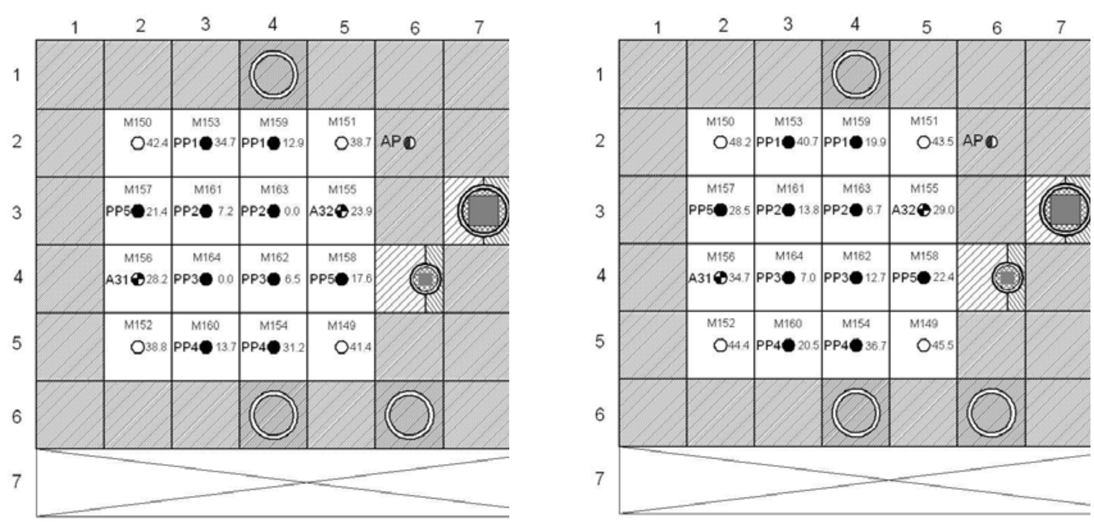
The FA reloading order in the IR-8 core for neutronic calculations of the cycle # 31M:
Loading of fresh FA ➔ 3-3 ➔ 2-3 ➔ 2-2 ➔ Unloading of FA with burnup 52%
Loading of fresh FA ➔ 4-4 ➔ 5-4 ➔ 5-5 ➔ Unloading of FA with burnup 45%



Beginning of cycle (ρ = 7.11 %Δk/k) End of cycle (ρ = 1.78 %Δk/k)

Figure 12. The FA fuel burnup for operating reactor cycle # 31M.
The cycle length – 58 FPD's. Energy generation – 290 MW-days.

The FA reloading order in the IR-8 core for neutronic calculations of the cycle # 32M:
Loading of fresh FA → 4-3 → 4-2 → 5-2 → Unloading of FA with burnup 49%
Loading of fresh FA → 3-4 → 3-5 → 2-5 → Unloading of FA with burnup 47%

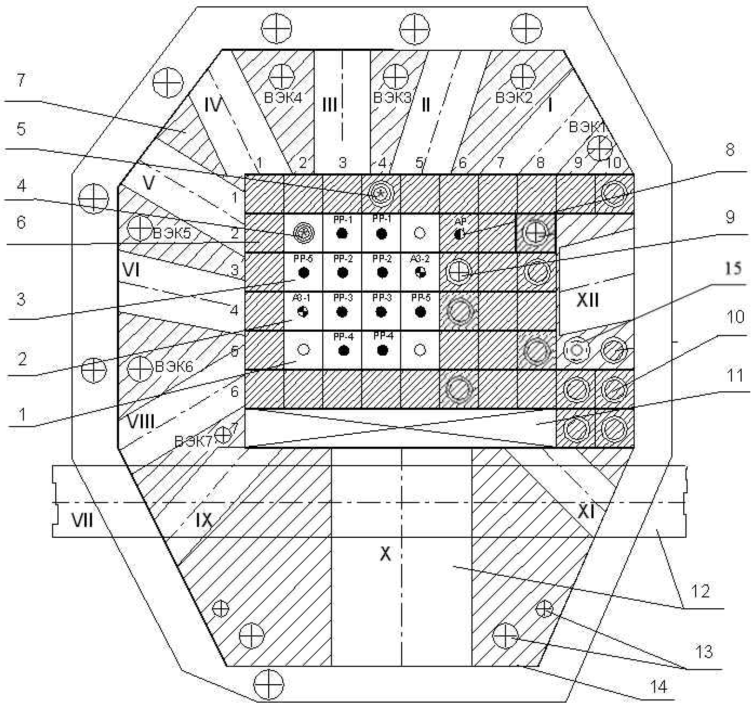


Beginning of cycle (ρ = 7.08 %Δk/k) End of cycle (ρ = 1.79 %Δk/k)

Figure 13. The FA fuel burnup for operating reactor cycle # 32M.
The cycle length – 58 FPD's. Energy generation – 290 MW-days.

6. Parameters of the IR-8 reactor equilibrium cycle with LEU U-9%Mo IRT-3M type FA’s

Parameters of the IR-8 reactor (fig. 14) for equilibrium cycles are presented at Tables 2 and 3.



1 - IRT-3M six-tube FA; 2 - IRT-3M six-tube FA with safety rod; 3 - IRT-3M six-tube FA with shim-safety rod; 4 - IRT-3M four-tube FA with an ampoule rig (AR); 5 - beryllium block with an ampoule rig; 6 - beryllium block 69×69 mm; 7 - block of stationary beryllium reflector; 8 - beryllium block with automatic regulating rod; 9 – beryllium block with experimental channel (EC); 10 - beryllium blocks with plugs; 11 - lead shield; 12 - beam tubes; 13 – holes for experimental channels (VEK); 14 – reactor vessel; 15 – experimental channels.

Fig 14. Cross section of the IR-8 core and of the reflector

Table 2. The main neutronic parameters of the IR-8 reactor for equilibrium cycles with LEU at the power of 6 MW

Parameter	Value
Reactor power, MW	up to 6
Megawatt days per cycle	290
Cycle length, FPD’s	48.3
Burnup of unloading FA, %	~50
Hours of operation per year	4000
Cycles per year	3.45
FA consumption per year,ps.	6.9
Excess reactivity, %Δk/k:	
- the beginning of cycle	7.1
- the end of cycle	1.8
Total reactivity worth of control rods, %Δk/k: - safety rods - shim and automatic rods	 3.9 24.2
Shutdown margin, %Δk/k	17.1

The statistical uncertainty of neutron fluxes calculations using MCU-PTR code (δ) equals one standard deviation (Table 3).

Table 3. . The results of the calculating of maximum flux density of thermal and fast (E> 0.5 MeV) neutrons at the power of 6 MW

Position	Neutron flux density n/(cm^2·s)			
	thermal	δ, %	fast	δ, %
VEC: 1	8.46E+12	0.36	7.26E+10	4.42
2	1.50E+13	0.27	1.51E+11	3.13
3	3.70E+13	0.17	6.60E+11	1.49
4	3.33E+13	0.16	5.68E+11	1.40
5	3.22E+13	0.18	5.35E+11	1.66
6	3.43E+13	0.16	5.69E+11	1.40
7	5.02E+13	0.19	1.32E+12	1.58
8	5.78E+12	0.55	1.99E+10	5.46
Beam tube (end): 1	3.86E+13	0.10	1.65E+12	0.75
2	7.86E+13	0.07	9.06E+12	0.31
3	9.30E+13	0.07	1.35E+13	0.26
4	7.38E+13	0.07	9.30E+12	0.30
5	7.98E+13	0.07	9.30E+12	0.30
6	8.94E+13	0.07	1.38E+13	0.25
8	7.50E+13	0.07	8.88E+12	0.31
9	4.27E+13	0.09	3.34E+12	0.49
Samples in AR:				
6-4 cell	7.62E+12	0.46	1.93E+13	0.59
7-3 cell	4.96E+12	0.44	6.24E+12	0.75
Be plug in block (6-3 cell)	5.05E+13	0.13	2.57E+13	0.22
Be plug in block (4-6 cell)	7.98E+13	0.09	3.34E+13	0.20
Al rod 6 mm dia in dry channel in centre of Be block (2-1 cell)	9.36E+13	0.17	3.26E+13	0.63
Aluminum tube 21.5 mm dia,in FA centre:				
2-2 cell	7.14E+13	0.19	8.16E+13	0.32
5-5 cell	5.46E+13	0.21	6.54E+13	0.36

Referensies

[1] Ryazantsev E.P., Nasonov V.A., Egorenkov P.M. et al. Contemporary Status and Employment Perspectives of the IR-8 Reactor of RRC KI. International Scientific Conference "Research Reactors in the XXI Century." Moscow, June 20-22, 2006. Ed. NIKIET, M., 2006.

[2] Nasonov V.A., Erak D.Y., Taliev A.V., Pesnya Y.E., Dubovskiy Y.M. The ongoing status of the project on feasibility studies for the conversion of the IR-8 reactor to LEU fuel. The Paper on International Scientific Conference “Research Reactors Fuel Management” RRFM-2011, Roma (Italy), March 20 – 24, 2011.

[3] Alexeev N.I., Gomin E.A., Marin S.V., Nasonov V.A., Shkarovsky D.A., Yudkevich M.S. MCU-PTR Code for Precision Calculation of Pool and Tank Types Research Reactors. - Atomic Energy, vol. 109, is. 3, 2010, p. 123-129.

[4] Egorenkov P.M., Nasonov V.A., Ryazantsev E.P., Taliev A.V. The Work in RRC “Kurchatov Institute under The Program Reduced Enrichment of Fuel for Research Reactors” – Preprint IAE-6590/4, Moscow, 2009.

[5] Nasonov V.A., Ryazantsev E.P., Taliev A.V., Egorenkov P.M. The Work under "The Program Reduced Enrichment of Fuel for Research Reactors" to 19.7% in RRC "Kurchatov Institute" – Atomic Energy, 2010, v.108, is. 3, p. 299-303.
[6] Nasonov V.A., Ryazantsev E.P., Taliev A.V., Yashin A.F. Water velocities determination in the gaps of IRT-3M and IRT-4M FA. Atomic Energy, 2011, v.110, is. 6, p. 317-321.