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LEU Transition Core Optimization for the WWR-M Research Reactor in Ukraine

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ABSTRACT

Because of full-core conversion of the WWR-M reactor in Ukraine with simultaneous replacement of all remaining HEU fuel by fresh LEU fuel, the number of fuel assemblies in the core and total power of the reactor were lowered essentially. As a result, fast and intermediate neutron fluxes in beam tubes were decreased essentially. With fuel burnup, the number of fuel assemblies in the core and reactor power will be increased, so for equilibrium LEU core, flux in beam tubes will be almost the same as for HEU core. However, to solve this problem during transient period, core reload optimization should be applied. Thus, dependence of the number of fuel assemblies in the core and maximum allowed power of the reactor on LEU fuel burnup is estimated using calculations by MCNP-4C, WIMS-ANL and PLTEMP codes. Then, core configuration is optimized successively with increasing fuel burnup to provide sufficient fast and intermediate neutron flux in beam tubes and satisfy all the safety requirements.

1. Introduction

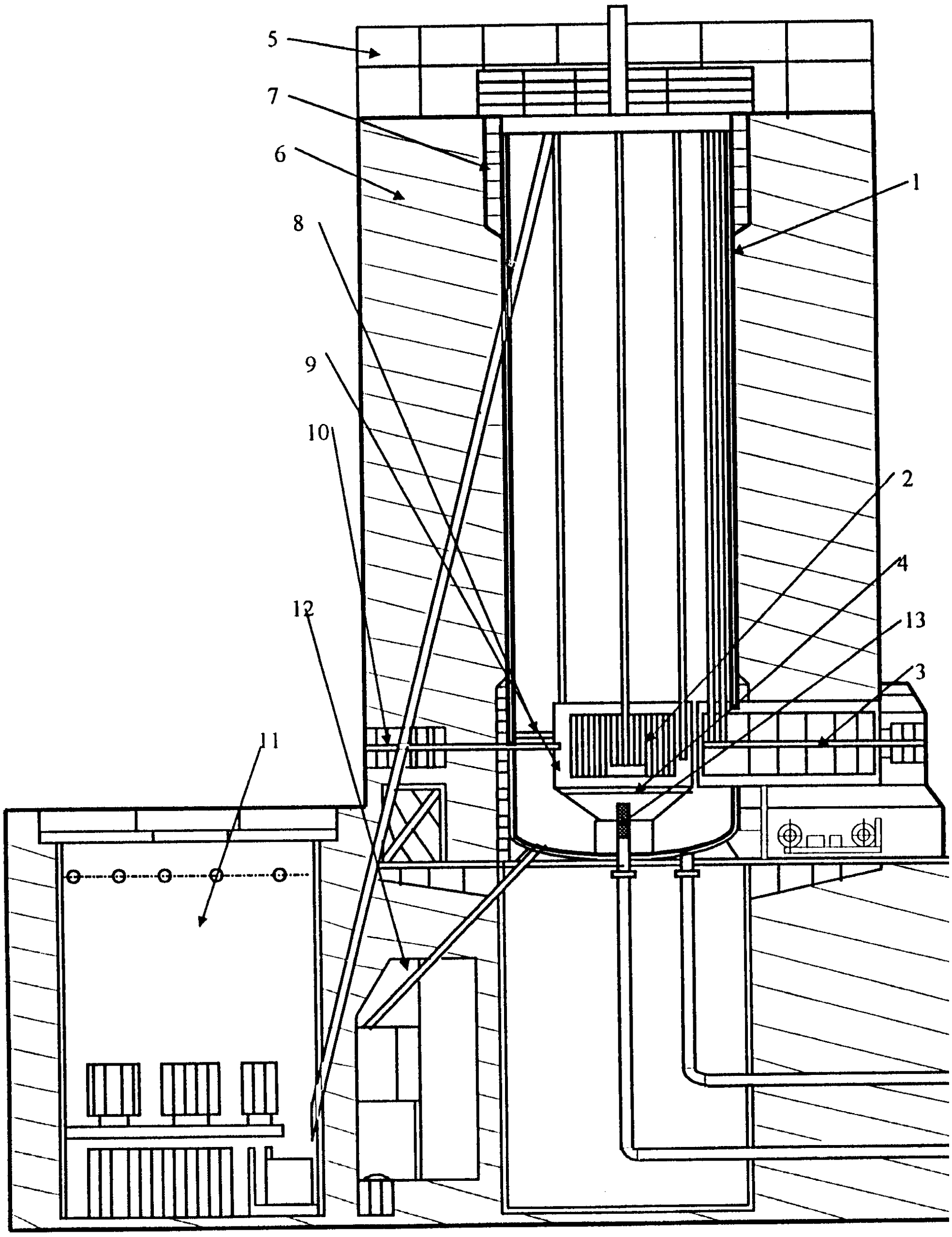
The WWR-M reactor in Kiev (Ukraine) is a light-water cooled and moderated research reactor with beryllium reflector. Its maximal power is 10 MW. Replaced HEU fuel assemblies are WWR-M2 (36%). LEU replacement fuel assemblies are LEU WWR-M2 (19.75%), which have been tested successfully in the WWR-M reactor in Gatchina, Russia by irradiation to over 75% burnup [1]. The reactor and fuel assembly parameters and designs are shown in Fig.1-3 and Table 1 [1-3].

Study confirming feasibility of converting the WWR-M research reactor in Ukraine to the use of LEU fuel was completed in 2002 [4]. Safety analysis to qualify LEU WWR-M2 fuel assemblies for conversion was performed in 2004-2005 [5-6]. Safety of fresh and depleted LEU fuel storage was analyzed also [6]. The models applied for calculations were validated against measured data, which include critical experiment results for fresh fuel assemblies and measured neutronic distributions in a real WWR-M reactor core [6]. Safety documentation for LEU conversion of the WWR-M reactor was approved officially by the Nuclear Regulatory Committee of Ukraine in 2005.

In accordance with the program of pilot usage of LEU fuel approved by the Ukrainian Regulatory Committee in 2008, most burned HEU fuel assemblies of the WWR-M reactor were successively replaced by fresh LEU fuel. However, such the conversion progressed very slowly.

Thus, the new full-core conversion program with simultaneous replacement of all remaining HEU fuel by fresh LEU fuel was developed in 2010 [7] and realized in 2011 [8].

Because of simultaneous replacement of all remaining HEU fuel by fresh LEU fuel, the number of fuel assemblies in the core and total power of the WWR-M reactor were lowered essentially. As a result, fast and intermediate neutron fluxes in beam tubes were decreased essentially. With fuel burnup, the number of fuel assemblies in the core and reactor power will be increased, so for equilibrium LEU core, flux in beam tubes will be almost the same as for HEU core. However, to solve this problem during transient period, core reload optimization should be applied.



1 – Reactor Vessel

2 – Reactor Core

3 – Thermal Column

4 – Supporting Plate

5 – Cover

6 – Shield

7 – Cast Iron

8 – Grid for Water Flow Alignment

9 – Beryllium Reflector

10 – A Beam Tube

11 – Spent Fuel Storage

12 – Hot Cell

13 – Filter

Fig. 1. WWR-M reactor

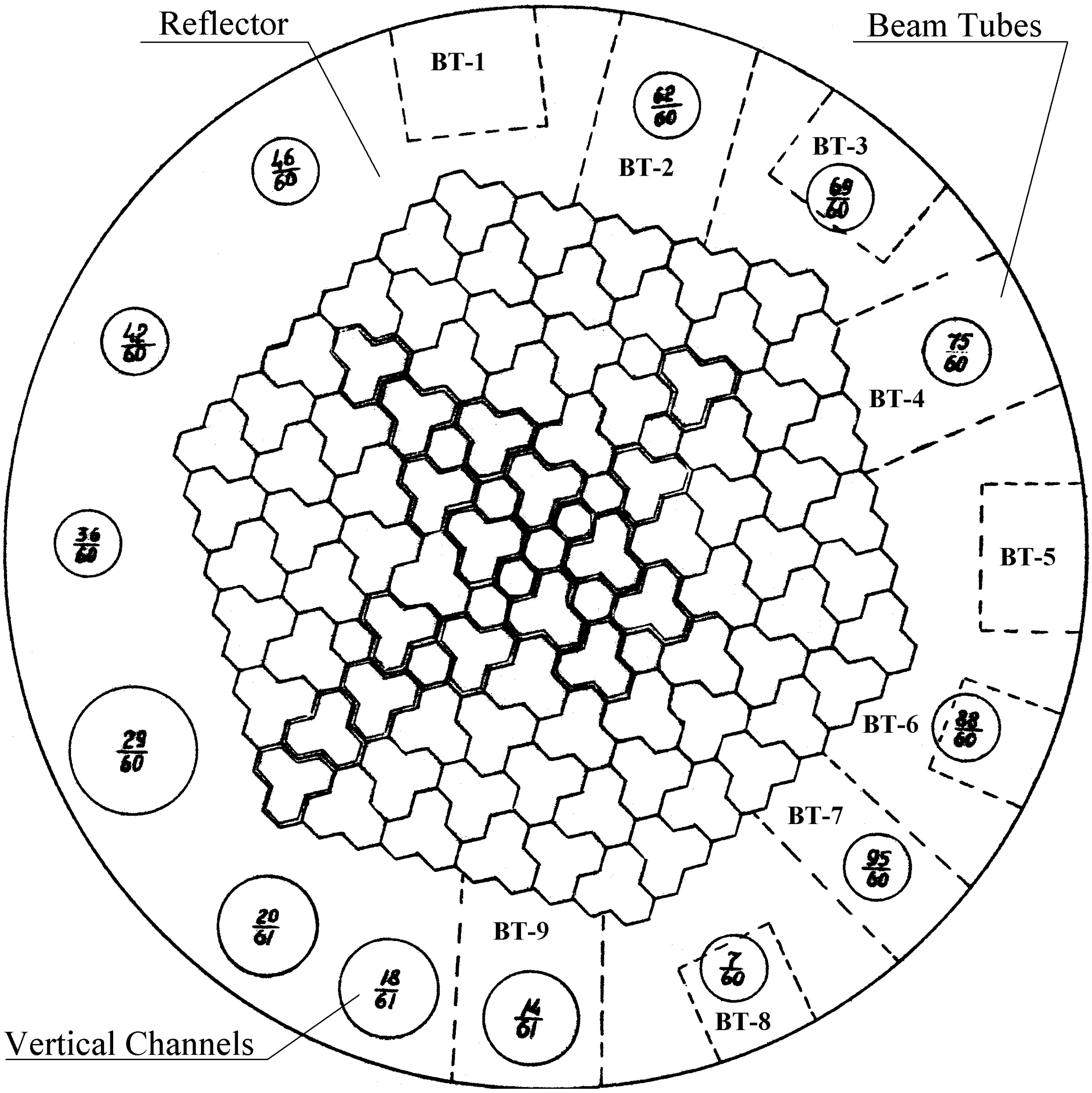


Fig. 2. Reactor core and beryllium reflector

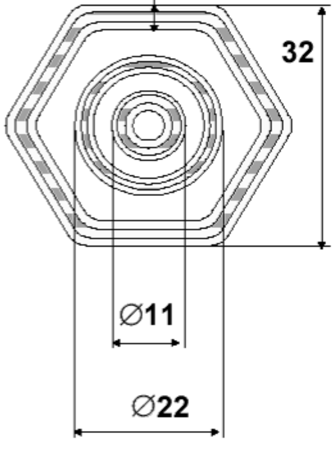


Fig.3. WWR-M2 fuel assembly

Table 1. Fuel assembly parameters

	HEU WWR-M2	LEU WWR-M2
Enrichment, %	36	19.75
Number of fuel elements	3	3
Mass of ^{235}U, g	37	41.7
Fuel meat composition	UO_2-Al 1.1 gU/cm^3	UO_2-Al 2.5 gU/cm^3
Length of fueled region, cm	50	50
Pitch/flat-to-flat, mm	35/32	35/32
Element/clad/meat, mm	2.5/0.76/0.98	2.5/0.78/0.94
Hydraulic resistance coefficient	4.35	4.35
Relative coolant velocities between fuel elements (starting from the center)	1.18;0.89;1.05;0.86	1.18;0.89;1.05;0.86

2. Transient Core Optimization

At first, dependence of the number of fuel assemblies in the core and maximum allowed power of the reactor on LEU fuel burnup is estimated using calculations by MCNP-4C [9], WIMS-ANL [10] and PLTEMP/ANL 2.1 [11] codes, as shown in Fig.4. Using this dependence, it is estimated how transient core configuration should be changed with LEU fuel burnup to provide sufficient fast and intermediate neutron flux in beam tubes, as shown in Fig.5-11.

Then, placement of fuel assemblies and beryllium blocks in the core is optimized for each core reload during transient period to satisfy all the safety requirements and provide high neutronic performance of the reactor. Relative intermediate and fast neutron fluxes for the transient LEU core configurations are shown in Tables 2 and 3. They are determined as ratio of fluxes for the transient LEU and equilibrium HEU cores, calculated by MCNP-4C.

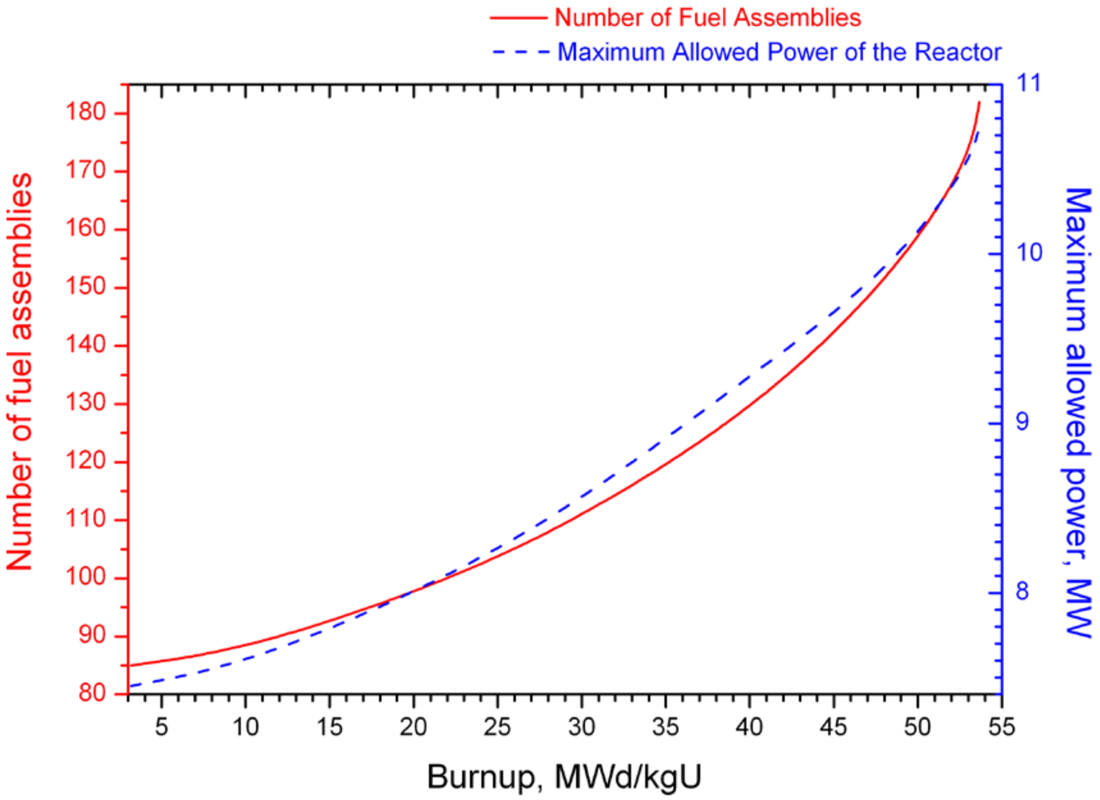


Fig.4. Dependence of the number of fuel assemblies in the core and maximum allowed power of the reactor on LEU fuel burnup

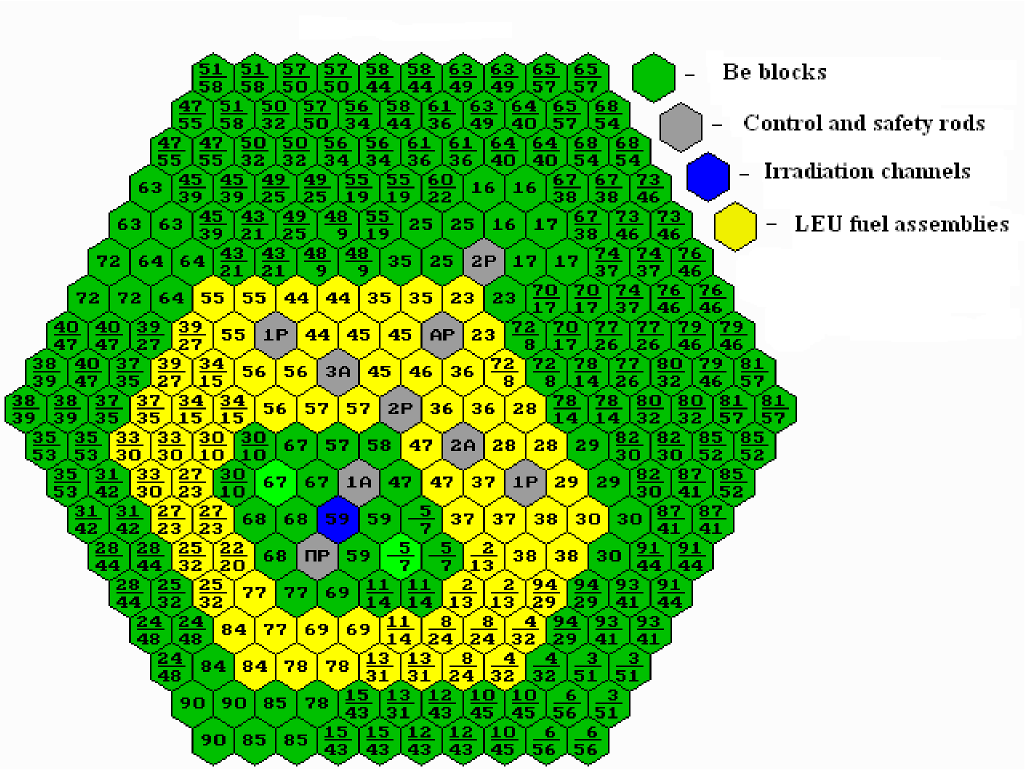


Fig.5. LEU core with 72 fuel assemblies

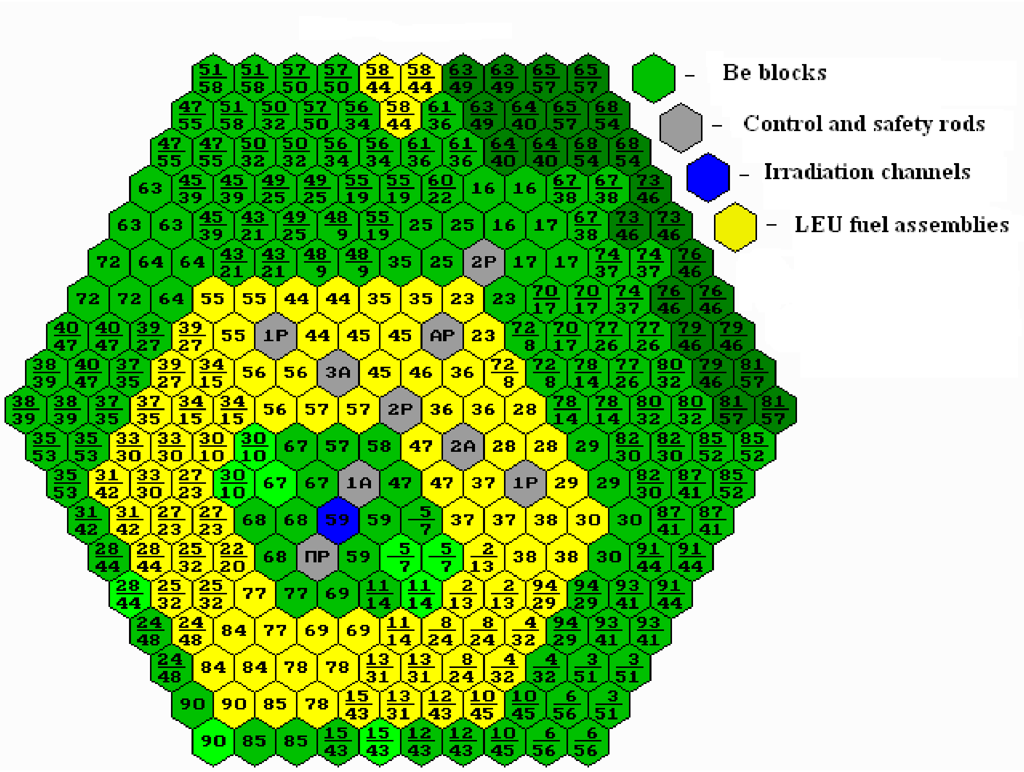


Fig.6. LEU core with 88 fuel assemblies

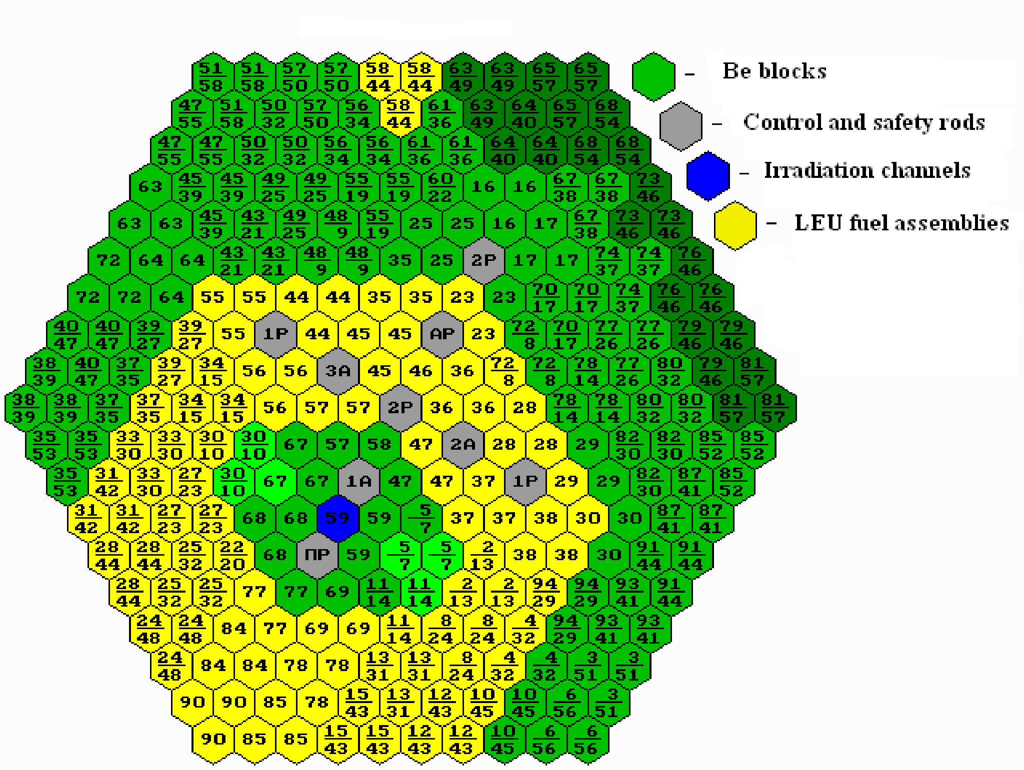


Fig.7. LEU core with 101 fuel assemblies

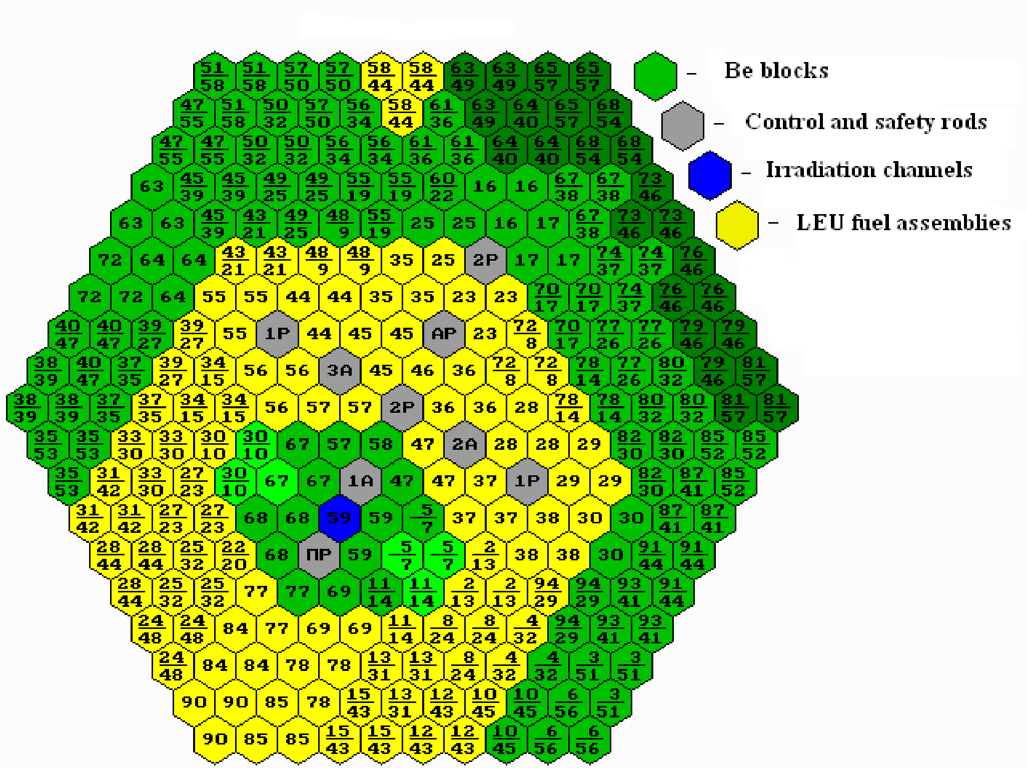


Fig.8. LEU core with 113 fuel assemblies

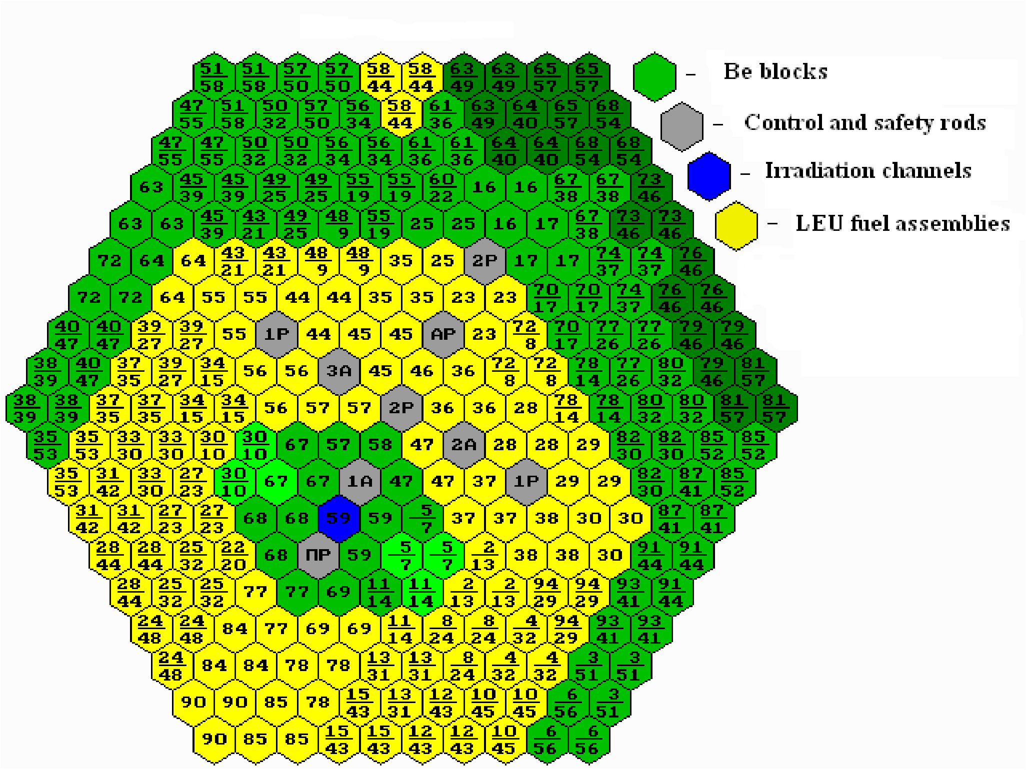


Fig.9. LEU core with 127 fuel assemblies

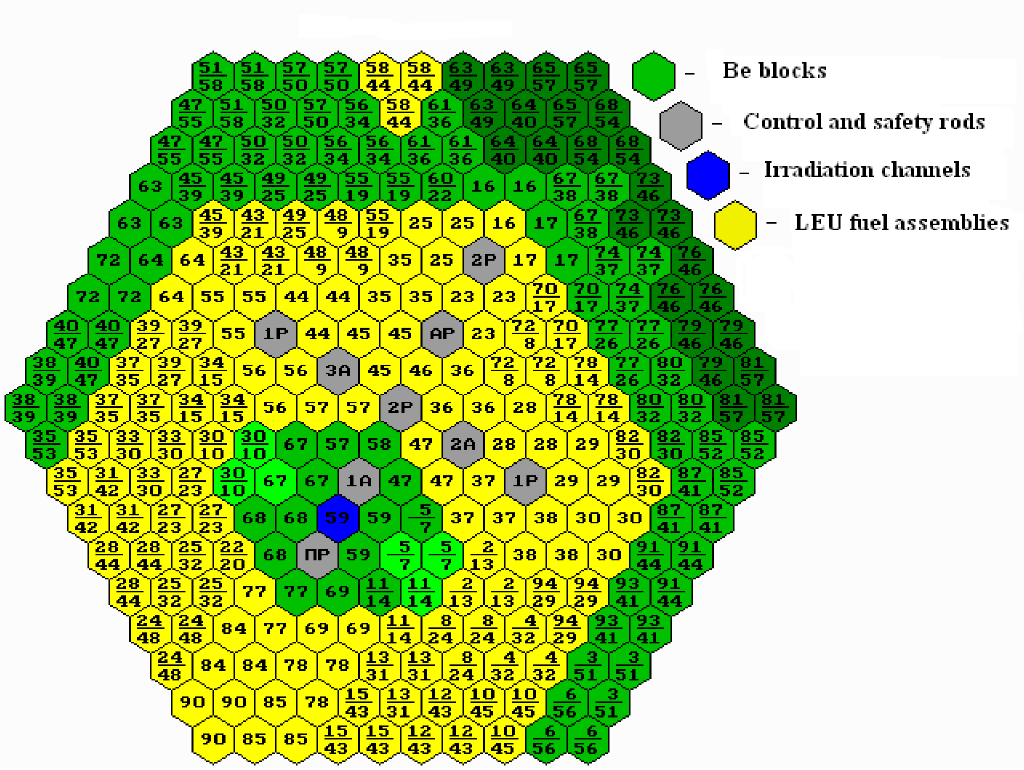


Fig.10. LEU core with 142 fuel assemblies

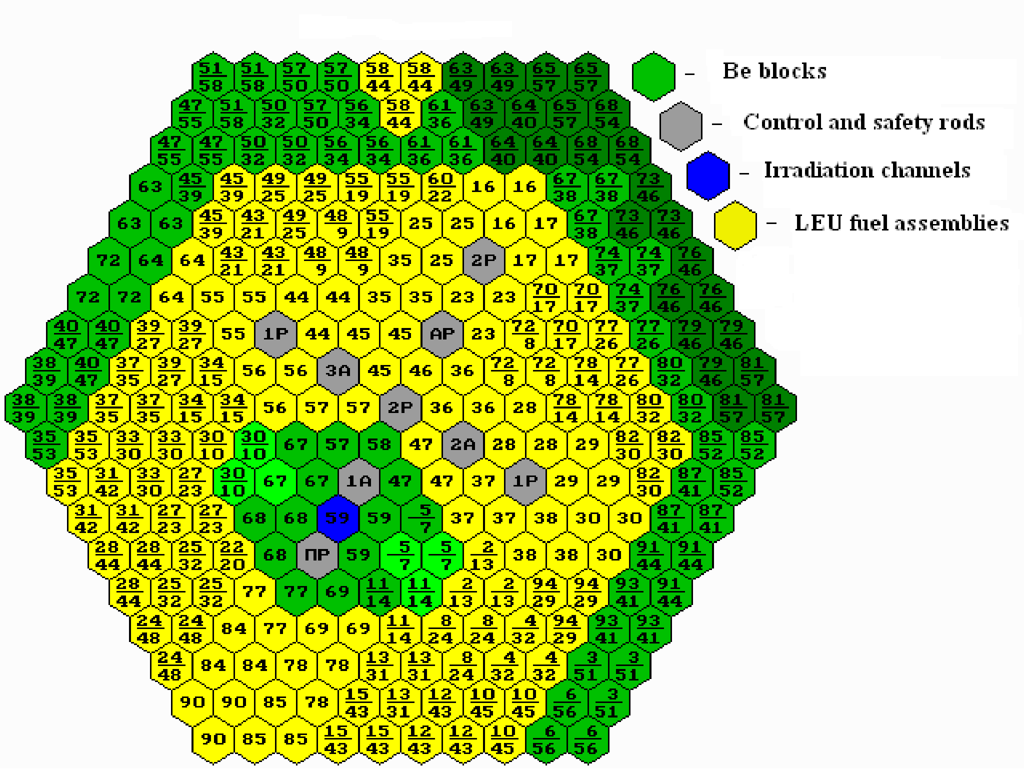


Fig.11. LEU core with 157 fuel assemblies

Table 2. Relative intermediate flux (0.2 eV <E < 0.8 MeV) ,%

	72 FA	88 FA	101 FA	113 FA	127 FA	142 FA	157 FA
BT1	47	64	55	81	91	127	166
BT2	27	62	53	74	73	101	131
BT3	16	28	25	37	36	57	82
BT4	24	25	22	36	35	60	93
BT5	60	53	48	78	81	128	188
BT6	118	114	102	145	174	244	309
BT7	75	72	69	81	111	127	133
BT8	70	78	81	83	113	112	106
BT9	84	107	135	129	148	141	130
62/60	19	54	47	63	64	86	115
69/60	15	25	22	34	32	51	77
75/60	16	17	15	25	25	45	74
88/60	129	119	108	159	185	266	335
95/60	84	81	76	90	121	137	146
7/60	68	72	75	75	104	104	99
14/61	74	96	124	119	140	134	122
18/61	78	113	166	155	159	150	136
20/61	76	116	182	170	165	153	137
29/60	83	115	167	156	155	145	130
36/60	64	83	107	102	125	121	111
42/60	57	58	59	61	90	90	86
46/60	53	50	45	57	80	98	106

Table 3. Relative fast flux (E > 0.8 MeV), %

	72 FA	88 FA	101 FA	113 FA	127 FA	142 FA	157 FA
BT-1	24	37	33	49	55	81	116
BT-2	11	49	41	57	56	76	102
BT-3	7	16	14	21	21	34	52
BT-4	10	10	9	15	15	29	49
BT-5	32	27	26	44	45	78	125
BT-6	62	63	58	87	109	157	218
BT-7	54	51	49	57	86	101	106
BT-8	47	51	52	55	83	86	82
BT-9	55	76	110	103	133	125	116
62/60	11	46	39	54	52	69	97
69/60	7	13	11	18	18	28	45
75/60	9	9	8	15	15	28	51
88/60	72	68	58	89	112	169	224
95/60	55	51	48	58	88	103	109
7/60	43	44	45	46	72	72	69
14/61	51	72	104	100	126	121	110
18/61	59	92	161	150	155	146	132
20/61	54	91	180	167	163	151	135
29/60	52	87	170	160	159	148	133
36/60	44	61	90	86	117	112	101
42/60	34	35	36	37	62	62	59
46/60	30	30	27	35	53	68	75

3. Conclusions

Full-core conversion of the WWR-M reactor in Ukraine with simultaneous replacement of all remaining HEU fuel by fresh LEU fuel decreased fast and intermediate neutron fluxes in beam tubes essentially. To solve this problem, transient core reload optimization is applied. Dependence of the number of fuel assemblies in the core and maximum allowed power of the reactor on LEU fuel burnup is estimated. Using this dependence, it is estimated how transient core configuration should be changed with LEU fuel burnup to provide sufficient fast and intermediate neutron flux in beam tubes. Placement of fuel assemblies and beryllium displacers in the core is optimized for each core reload during transient period to satisfy all the safety requirements and provide high neutronic performance of the reactor.

4. References

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