Neutronic Analysis For The Conversion of IAEA 10 MW Research Reactor From HEU to LEU

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Contents:

Purpose of the Paper

- Design an exact and heterogeneous Model to Plate type Research Reactor and Compare The Neutronic Parameters with a Benchmark Homogeneous Model.

- Simulate The Reactor Conversion Processes From HEU to LEU.

Introduction

Neutronic and Burnup analysis are provided for Conversion Processes of the plate type MTR IAEA 10 Mw Benchmark research reactor from High Enrichment uranium (HEU) fuel to low enrichment (LEU) uranium fuel. The Core Consists of 5x 6 fuel Elements (28 for Fuel and 2 Irradiation Channel).

- **<u>The High Enrichment Uranium Core (HEU)</u>** **Consists of 28 Fuel Elements . (23 Standard Fuel Elements and 5 Control Elements) Fuel element Dimensions 7.71 x8.1 cm with core dimensions 46.26x40.5 cm with active length 60 cm**

- **Standard Fuel Element Contains 23 Plates and Control Fuel Element Contains 17 Plates and 4 Control Plates.**

- **The Fuel are in the form of UAlx-Al with enrichment 93 % which Contains 280 gm ^{235}U per standard Fuel and 207 gm ^{235}U per Control Fuel.**

- **The Plate Thickness is 1.27 mm, Water Channel thickness 2.19 mm, meat Thickness 0.51 mm and Uranium Density in The Meat is 0.68 gm/cm^{3}**

- <u>Low Enrichment Uranium Core</u> (LEU) Consists of 28 Fuel Elements(23 Standard and 5 Control) , Element dimensions 8.1 cm x7.71 cm.
- Standard (LEU) contains 20 Plates while Control Element contains 14 fuel plates and 4 control plates.
- Fuel is in the form of U_3O_8 with enrichment 19.7 % Standard element Contains 446 gm ^{235}U while Control Element contains 312.2 gm ^{235}U per Element.
- Plate Thickness 1.76 mm (1.99 mm outer plates). Water channel thickness 2.217 mm. Uranium density in the meat 3 gm /cm^3 meat thickness 1.0 mm.
- More details for core Compositions References (1,2,3).

Mathematical and Computer Model

MCNPX computer code is used to model the reactor conversion process from high enrichment fuel (HEU) to low enrichment fuel (LEU) . Three dimensional and typical model for the reactor geometry and dimensions is designed.

- ✓ The core is reflected by graphite in two faces and water in the other faces. 20 cm water layer thickness is assumed above and below the reactor core. Four million neutron histories are used to simulate the core and accumulate the reactor tallies.
- ✓ FIG. 1 illustrates core set up, i. e. the HEU reactor core Burnup in ^{235}U per cent consumption at both beginning of equilibrium cycle (BOC) for upper values and End of cycle (EOC) for Lower values.

C	C	C	C	C	C
0.0 10.8	24 34.5	0 16.2	36 46.7	12 23.3	0 10.5
12 23.8	36 47.5	48 59.7	48 61.3	36 48.9	12 23.8
24 35.5	48 59.8	48 62.5		36 50.4	24 35.4
0 12.9	24 36.1	48 59.3	48 60.9	24 38.2	12 23.6
	0 12.9	12 25.8	36 46.3	24 34	0 10.3
C	C	C	C	C	C

FIG.1. Burnup Distributions (% U^{235} consumptions) for HEU core at beginning of Cycle BOC (upper values) and End of Cycle EOC (lower values)

For Burnup Calculations , the Cycle length is 69 , 80 , 76, 90 , 105 and 118 days respectively which corresponds to Pure HEU core , four mixed cores and LEU core respectively.

For every Core Cycle 4 LEU element are Loaded into the reactor core and 4 HEU are discharged from the Core and the fuel are shuffled in the mixed core according to reference (3).

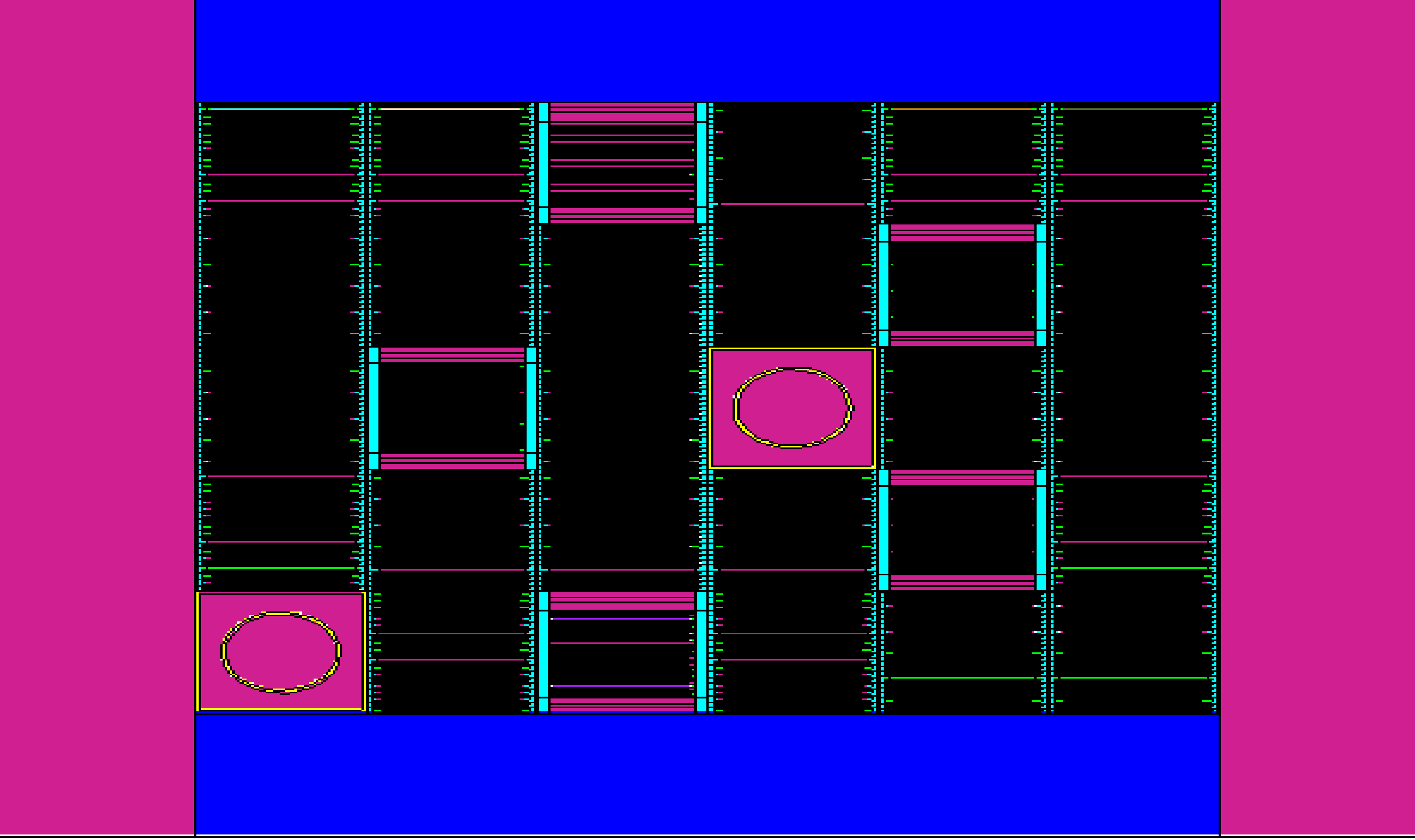

FIG. (2.a) Horizontal Cross Section for MCNPX Computer Model

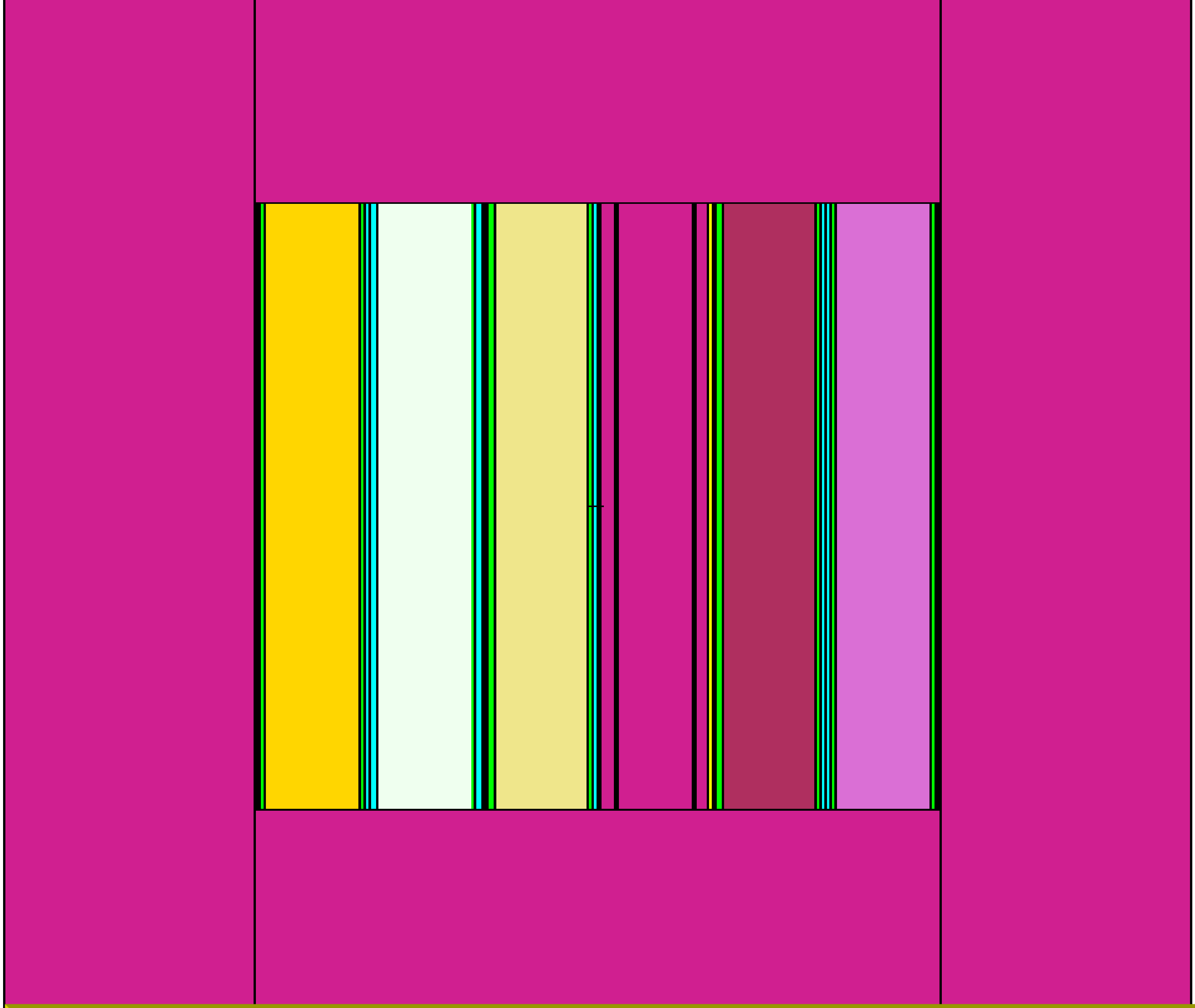

FIG. (2.b) Vertical Cross Sections of the Core

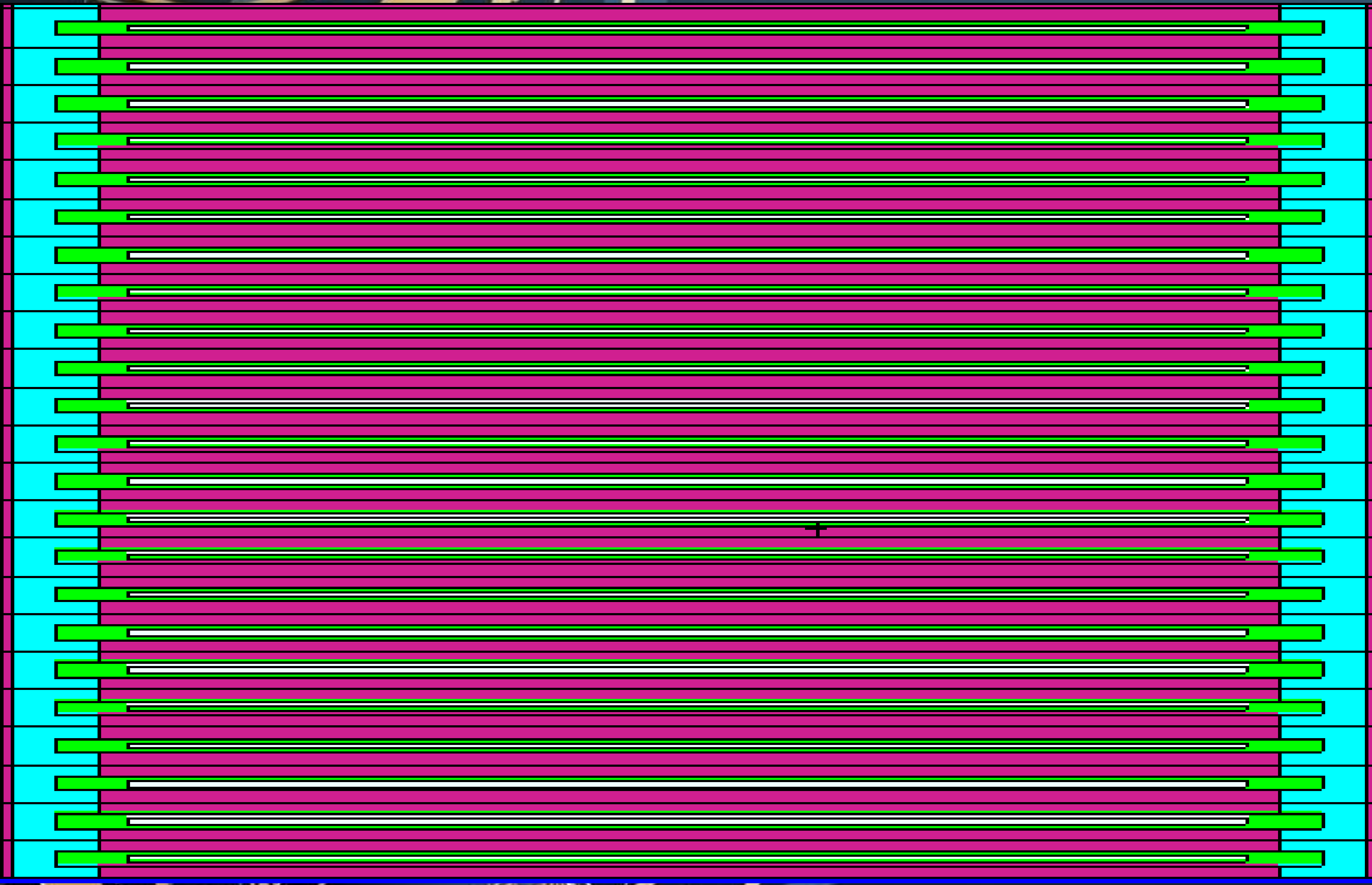

FIG.(3.a) Standard HEU Fuel Element   (23 Plates)

Fig. (3.b) Control HEUFuel Element (17 Plates)

Fig. (4.a) Standard LEU Fuel Element (20 plates)

FIG (4.b) Control (LEU) Fuel Elements 14 Plates

RESULTS and DISCUSSIONS

The Results cover three Types of Calculations:

1. **Calculation of Reactor Multiplication factor through Conversion process(6 cycles).**
2. **Fuel Element Power distribution at Beginning and End of each Cycle.**
3. **Fuel Burnup at Beginning and End of each Cycle.**

Calculation of Reactor Multiplication factor through Conversion process (6 cycles).

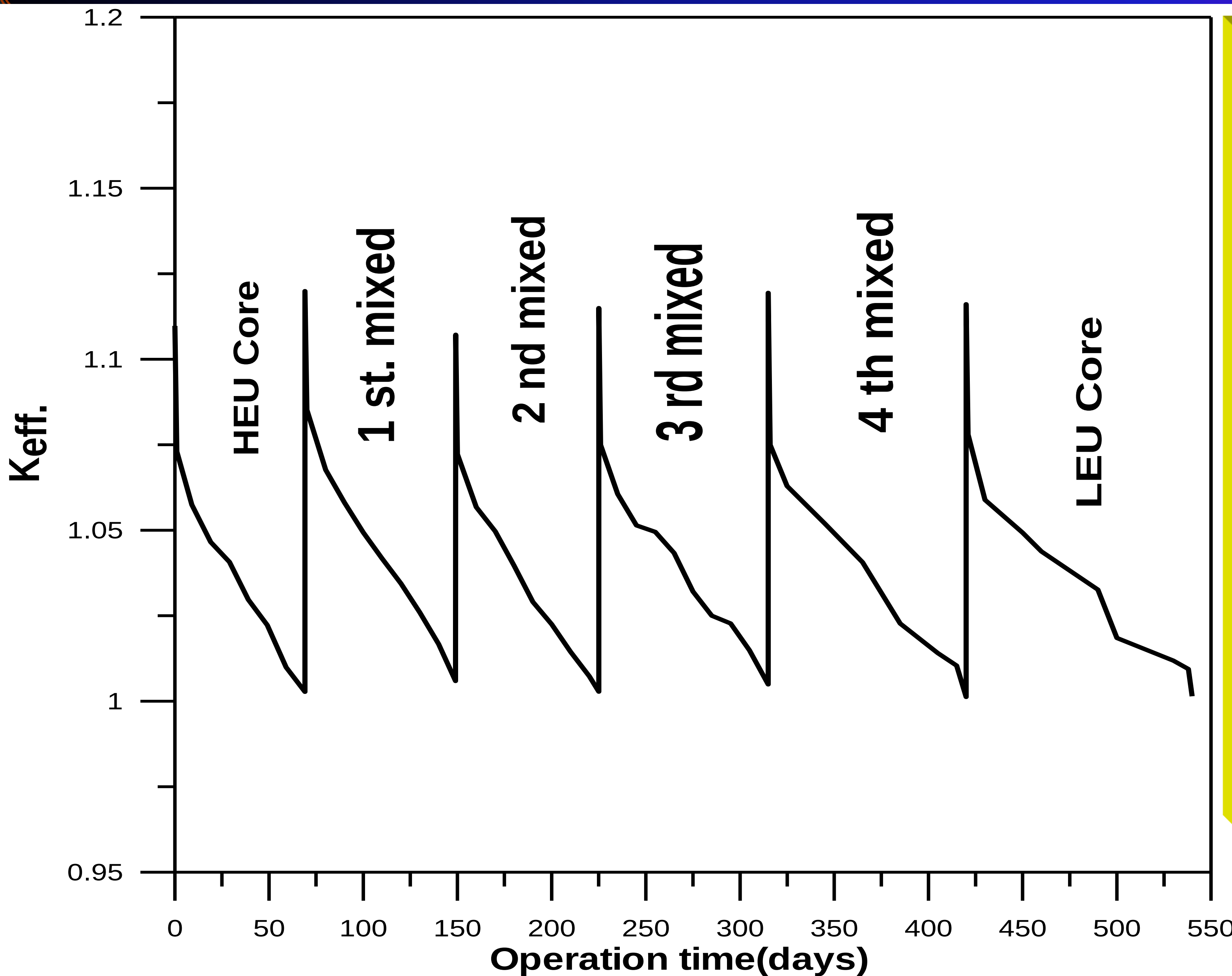

FIG. 5 $K_{eff.}$ Versus operation time of the core (days)

- FIG. 5 illustrates core multiplication factor $K_{eff.}$ Versus different core cycles. As shown in the figure HEU core represents full high enrichment core fuel. The next 4 cycles represents mixed HEU and LEU fuel assemblies. The 6^{th} cycle represents LEU fuel assemblies. The present results are in good agreement with reference [3]. The maximum difference between the two results are 500 pcm (at 6 th cycle)

Results of The First Cycle HEU Core

C	C	C	C	C	C
0.84 0.87	0.90 0.87	1.336 1.33	0.94 0.89	0.966 0.94	0.79 0.87
1.082 0.98	1.216 0.97	1.249 0.99	1.29 1.11	0.926 1.08	1.035 0.98
1.106 0.96	0.943 0.99	1.427 1.21		1.429 1.2	1.0465 0.94
1.169 1.07	1.269 1.01	1.212 0.95	1.275 1.08	1.363 1.19	1.031 0.96
	1.031 1.07	1.189 1.16	0.9178 0.87	0.898 0.86	0.782 0.90
C	C	C	C	C	C

FIG. 6 Comparison between the power distributions(normalized) at BOC for HEU core. (Upper values: Present Model) , (Lower values:

C	C	C	C	C	C
0.839 0.93	0.882 0.90	1.285 1.33	0.95 0.89	0.961 0.97	0.799 0.91
1.083 1.02	1.147 0.96	1.124 0.94	1.136 1.02	1.173 1.05	1.044 1.02
1.0756 0.98	1.136 0.94	1.227 1.09		1.298 1.14	1.036 0.97
1.149 1.1	1.22 1.02	1.105 0.91	1.119 1.0	1.294 1.17	1.034 1.0
	1.018 1.09	1.15 1.16	0.897 0.87	0.876 0.86	0.8 0.9
C	C	C	C	C	C

FIG. 7 relative power distribution at EOC for HEU (Upper values: present model), (Lower values: reference [3])

C	C	C	C	C	C
9.3 10.8	33.5 34.5	14.0 16.2	45.6 46.7	22.4 23.3	9.1 10.5
23.7 23.8	47.9 47.5	59.9 59.7	60.1 61.3	48.6 48.9	23.3 23.8
35.5 35.5	59.8 59.8	61.6 62.5		50.1 50.4	35.4 35.4
12.7 12.9	36.8 36.1	59.6 59,3	59.9 60.9	37.9 38.2	22.9 23.6
	11.3 12.9	24.2 25.8	45.6 46.3	33.5 34.0	9.2 10.3
C	C	C	C	C	C

FIG. 8 Comparison between Burnup of ^{235}U for present (MCNPX model :Upper values) and (reference[3] : Lower values) for EOC in HEU core.

Results of The Second Cycle (First Mixed Core)

C	C	C	C	C	C
C	9.0 8.8	27.97 30.1	44.6 45.6	34.0 34.2	7.4 7.6
34.83 34.3	48.7 47.1	61.9 59.9	60.2 60.9	51.9 51.5	24.0 25.0
36.9 35.6	62.1 61.4	65.5 65.7		52.1 51.5	45.7 45.0
10.8 9.1	28.2 26.7	49.0 50.1	59.5 60.6	40.56 41.4	22.9 23.4
	9.3 9.9	10.5 11.6	10.2 10.34	34.2 34.5	19.6 21.4
C	C	C	C	C	C

FIG. 9 Burnup of ^{235}U for present (MCNPX model :Upper values) and (reference[3] : Lower values) for EOC of first mixed core.

C	C	C	C	C	C
C	1.17 1.1	0.824 1.03	0.89 0.83	0.857 0.79	0.994 0.96
0.994 0.85	1.047 0.86	1.01 0.88	1.1 0.97	0.813 0.96	1.022 .92
1.05 0.91	0.77 0.88	1.125 1.01		1.27 1.11	0.988 0.85
1.45 1.26	0.1.225 1.05	1.17 1.03	1.033 0.99	0.93 1.14	1.11 1.0
	1.194 1.26	0.944 1.48	1.294 1.31	0.847 0.84	0.832 0.85
C	C	C	C	C	C

FIG.10 Normalized power distribution for(present MCNPX model : Upper values) and (reference [3] : Lower values) for EOC of first mixed core.

Results of The Third Cycle (Second Mixed Core)

C	C	C	C	C	C
15.88 17.1	16.74 17.0	21.55 23.0	44.1 45.3	15.35 16.0	6.46 7.4
22.79 23.7	45.86 46.9	60.56 60.0	59.2 60.8	50.56 54.0	14.7 18.7
36.92 33.6	64.1 64.1	66.1 66.1		51.65 51.7	33.2 35.2
9.95 10.3	40.84 39.5	57.64 58.4	63.47 64.9	41.9 44.4	18.89 19.4
	8.4 10.0	9.22 11.8	9.1 10.3	29.6 32.4	41.54 43.0
C	C	C	C	C	C

FIG. 11 Comparison between Burnup of ^{235}U for present MCNPX model (Upper values) and (reference[3] : Lower values) for EOC of second mixed core.

C	C	C	C	C	C
0.897 0.94	1.034 1.04	1.063 1.45	0.827 0.81	1.095 1.07	0.91 0.93
1.037 0.96	1.037 0.91	1.036 0.89	0.999 1.0	0.755 0.88	0.993 1.12
1.0 0.92	0.71 0.85	1.08 1.0		1.2 1.09	1.003 0.88
1.38 1.24	1.044 0.92	1.029 0.89	0.93 0.89	0.857 1.03	1.26 1.14
	1.16 1.21	0.9 1.41	1.24 1.24	0.85 0.82	0.62 0.65
C	C	C	C	C	C

FIG. 12 Comparison between normalized power distribution for (present MCNPX model :Upper values) and (reference3 : Lower values) for EOC of second mixed core.

Results of the Fourth Cycle (Third Mixed Core)

C	C	C	C	C	C
7.65 8.5	25.37 25.6	22.5 24.2	27.95 28.3	18.8 18.58	8.4 7.38
20.6 20.2	51.28 51.0	61.37 61.6	60.49 62.1	57.55 58.4	17.13 17.2
37.3 37.4	50.1 49.4	67.47 69.5		52.1 52.8	26.3 25.7
11.2 11.0	32.7 27.6	54.6 54.6	57.7 59.7	35.1 35.8	19.9 19.8
	9.36 10.9	10.67 13.3	8.98 11.2	27.4 27.7	40.76 41.9
C	C	C	C	C	C

FIG.13 Comparison between Burnup of ^{235}U for(present MCNPX model :Upper values) and (reference[3] : Lower values) for EOC of third mixed core.

C	C	C	C	C	C
0.88 0.91	0.96 0.96	1.25 1.33	1.065 1.07	0.97 0.97	0.85 0.91
1.20 1.08	0.92 0.82	0.967 0.85	0.996 0.94	0.66 0.82	1.12 1.09
0.95 0.86	0.83 0.75	1.016 0.92		1.12 1.01	1.14 1.09
1.28 1.16	1.31 1.14	1.019 0.89	0.97 0.94	1.39 1.38	1.15 1.06
	1.104 1.14	1.26 1.33	1.19 1.18	0.96 0.94	0.61 0.63
C	C	C	C	C	C

FIG.14 Comparison between normalized power distribution for (present MCNPX model :Upper values) and (reference[3] :Lower values) for EOC of third mixed core.

Results of Fifth Cycle (Fourth Mixed Core)

C	C	C	C	C	C
25.1 25.5	25.1 25.5	33.8 33.3	29.5 30.0	21.2 20.9	8.7 9.8
18.65 18.7	40.0 38.6	64.18 66.2	65.7 69.9	48.97 47.8	18.3 19.4
32.0 32.4	62.25 62.1	56.33 61.2		41.67 40.0	30.58 30.2
12.19 11.8	40.2 39.0	66.8 69.7	55.4 61.1	40.65 37.6	20.36 21.5
	10.67 11.9	22.4 26.8	37.3 37.8	19.9 20.8	13.24 9.71
C	C	C	C	C	C

FIG. 15 Comparison between Burnup of ^{235}U for (present MCNPX model : Upper values) and (reference[3] : Lower values) for EOC of fourth mixed core.

C	C	C	C	C	C
0.79 0.82	0.85 0.86	0.88 1.4	1.1 1.08	1.004 0.95	0.87 0.94
1.11 0.97	1.27 1.07	0.845 0.74	0.85 0.79	0.983 1.23	1.1 1.06
1.13 1.01	0.58! 0.61	1.2 1.08		1.5 1.35	1.14 1.04
1.216 1.07	1.23 1.04	0.79 0.68	0.96 0.92	0.895 1.3	1.16 1.04
	1.049 1.08	1.148 1.26	0.99 1.0	0.979 0.94	0.70 0.93
C	C	C	C	C	C

FIG. 16 Comparison between normalized power distribution for present MCNPX model (Upper values) and reference[3] (Lower values) for EOC of fourth mixed core.

Results of Sixth Cycle (LEU Core)

C	C	C	C	C	C
0.746 0.86	0.792 0.84	1.175 1.32	0.846 0.89	0.892 0.89	0.732 0.87
0.986 0.93	1.108 0.9	1.146 0.96	1.251 1.17	1.158 1.13	0.962 0.98
1.011 0.95	1.16 1.04	1.367 1.26		1.413 1.26	0.985 0.96
1.086 1.06	1.145 0.94	1.14 0.94	1.24 1.15	1.235 1.21	0.954 0.97
	0.934 1.06	1.0526 1.18	0.84 0.86	0.821 0.82	0.729 0.86
C	C	C	C	C	C

FIG.1 7 Power Peak factor for LEU core BOC(Upper values Present Model , Lower values reference).

C	C	C	C	C	C
0.756 0.9	0.788 0.86	1.134 1.33	0.817 0.89	0.874 0.92	0.726 0.90
0.98 0.97	1.07 0.91	1.097 0.94	1.133 1.11	1.097 1.11	0.9499 1.01
0.9977 0.97	1.078 1.0	1.222 1.18		1.29 1.21	0.963 0.98
1.07 1.08	1.116 0.95	1.078 0.92	1.126 1.09	1.176 1.2	0.942 0.99
	0.928 1.06	1.028 1.18	0.814 0.86	0.798 0.82	0.728 0.89
C	C	C	C	C	C

FIG. 18 Power Distributions for LEU at EOC

Conclusion

1- MCNPX computer code is used to design a heterogeneous model for a research reactor conversion

From HEU to LEU.

2- The multiplication factor of the reactor are calculated during transition and conversion process and a maximum difference between the reference homogenous model is 500 pcm.

3- the power distribution and fuel burnup are calculated during all conversion process and it is in agreement with the reference results.

THANKS