NEUTRONIC ANALYSIS FOR THE CONVERSION OF IAEA 10 MW RESEARCH REACTOR FROM HEU TO LEU

M. AZIZ
Atomic Energy Authority,
Nasr City,
Cairo,
Egypt

Abstract

A computer model was designed using MCNPX code to simulate and analyze the conversion process of HEU to LEU of IAEA 10 MW research reactor core. The conversion process are performed using six cycles. First cycle devoted for HEU core, four mixed cycles and the sixth cycle for LEU core. The multiplication factor of the core, the power distribution and fuel burnup were determined at both the beginning of cycle (BOC) and end of cycle (EOC) in the case of HEU and LEU. The results of the present model are compared with previously published results and good agreement was found.

1. INTRODUCTION

Neutronic and Burnup analysis are provided for the Conversion Processes of MTR IAEA 10 MW Benchmark research reactor from High Enrichment uranium (HEU) fuel to low enrichment (LEU) uranium fuel (1,2,3). The high enrichment reactor core contains 23 standard fuel elements and 5 control elements. The core is reflected by graphite on two opposite faces and is surround by water in the other faces. The HEU standard elements have 23 plates and the control elements contains 17 fuel plates. UAlx-Al Fuel enrichment is 93 % which contains 280 gm ^{235}U per standard fuel element and 207 gm ^{235}U per control element. The plate thickness is 1.27 mm, water channel thickness 2.19 mm, meat thickness 0.51 mm and uranium density in fuel meat is 0.68 gm/cm^3. LEU low enriched uranium fuel with enrichments 19.7% replaces the HEU gradually through the transition cores. LEU standard fuel element contains 20 plates while control elements contains 14 plates. U_3O_8–Al fuel meat. Uranium density in the meat is 3 gm/cm^3 and 446 g ^{235}U for standards fuel element and 312.2 gm for control element. Plates thickness 1.76 mm (inner) and 1.99 mm for outer plates. Water channel thickness 2.217 mm. One water filled flux trap is located near the center of the core and another near an edge in both LEU and HEU, both flux traps were replaced with 77 mm×81 mm blocks of aluminum with 50 mm square water holes in order to compute more realistic power peaking factors More details for HEU and LEU can be found at references (1,2,3).

Many researches are performed at different countries to convert the reactor core from high enrichment uranium to low enrichment core (4,5,6,7,8,9,10,11,12). In the following: section II describes the computer and Mathematical model which has been used in the calculations. Section III provides the results and discussions, and the conclusion and the references are also given at the end of the paper.

2. COMPUTER AND MATHEMATICAL MODEL

MCNPX computer code (13) 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 contains 28 fuel element and two experimental channels. The fuel element is represented by plates, for example, for the

HEU core the standard fuel element contains 23 plates while the control element contains 17 plates. For LEU core the fuel element contains 20 plates and the control element contains 14 plates. 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 Lowe values.

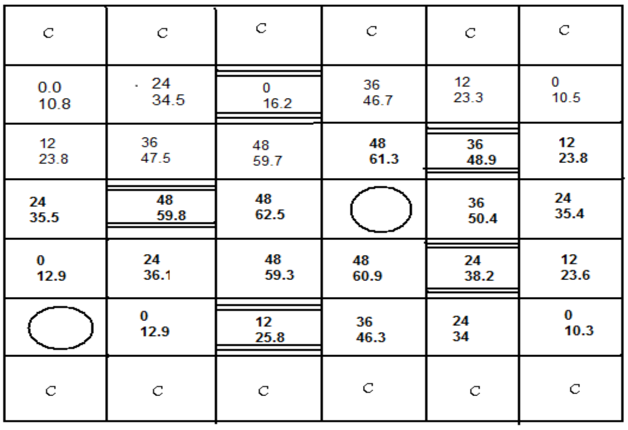

FIG. 1. Burnup Distributions (% U^{235} consumptions) for HEU core at beginning of Cycle BOC (upper values) and End of Cycle EOC (lower values).

3. RESULTS AND DISCUSSIONS

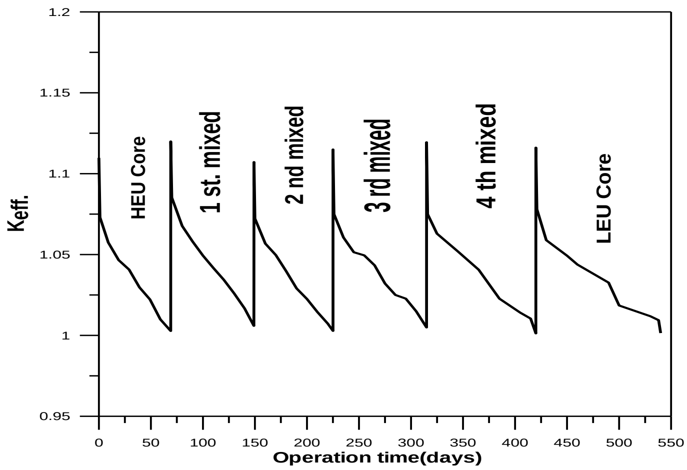

FIG. 2 $K_{eff.}$ versus operation time of the core (days).

FIG. 2 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 6th cycle represents LEU fuel assemblies. The distribution of fuel assemblies through core cycles and fuel shuffling schemes are given in reference 3. The present results are in good agreement with reference [3]. The maximum difference between the two results are 500 pcm.

3.1 High enrichment uranium core (HEU)

FIG. 3 illustrates the relative power distributions through the reactor core of HEU at beginning of cycle of the equilibrium core (BOC). The power is divided by the average power in the core. The power trends to maximize near the experimental water channel and decrease near core periphery. The results of the present model (upper values) are compared with the reference [3] .

FIG. 4 illustrates the relative power distribution for HEU at End of cycle EOC for equilibrium core. The power per fuel element is divided by average power in the core, the results of the present model are compared with reference.

FIG. 5 illustrates the burnup distribution in the core at EOC of HEU core, the figure compares between the results of present model (upper values) and the reference [3](lower values). The results indicates good agreement. The difference range between 0 and maximum value of 2.2 %.

3.2 Transition core

The reactor core is converted from HEU core to LEU core in four mixed (transition) core, for each of these mixed core , both HEU and LEU fuel exists in the core , several HEU fuel assemblies are replaced by LEU fuel assemblies and fuel assemblies are shuffled through the core the detailed of the four transition core are given in details at references No. 3. The following results represents the results of ^{235}U burnup atom per cent at EOC of each mixed core and the power distribution through the reactor core.

FIG. 6 Comparison between Burnup of ^{235}U atom for present MCNPX model (Upper values) and reference [3] (Lower values) for EOC of first mixed core. The results show difference in burnup percent of ^{235} U 2.1 %. FIG. 7 Comparison between normalized power distribution in the core for present MCNPX model (Upper values) and reference [3] (Lower values) for EOC of first mixed core.

FIG. 8 Comparison between Burnup of ^{235}U atom for present MCNPX model (Upper values) and reference[3] (Lower values) for EOC of second mixed core. FIG. 9 Comparison between normalized power distribution in the core for present MCNPX model (Upper values) and reference[3] (Lower values) for EOC of second mixed core.

FIG. 10 Comparison between Burnup of ^{235}U for present MCNPX model (Upper values) and reference [3] (Lower values) for EOC of third mixed core. The results shows good accuracy between the two methods the maximum difference is 5.1 %. FIG. 11 Comparison between normalized power distribution in the core for present MCNPX model (Upper values) and reference[3] (Lower values) for EOC of third mixed core.

FIG. 12 Comparison between Burnup of ^{235}U for present MCNPX model (Upper values) and reference[3] (Lower values) for EOC of fourth mixed core. FIG 13 Comparison between normalized power distribution for present MCNPX model (Upper values) and reference[3] (Lower values) for EOC of fourth mixed core.

3.3 Low enrichment uranium core

FIG. 14 illustrates the relative power in the fuel elements for LEU core at EOC, the results of the present model are compared with reference. Upper values for present model, and lower values for references.

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. 3. Comparison between the power peaking factor at BOC for HEU core

Upper values: Present Model, Lower values: [3]

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

Figure 4 relative power distribution at EOC for HEU

Upper values: present model, Lower values: [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. 5. Comparison between Burnup of ^{235}U for present MCNPX model (Upper values) and [3] (Lower values) for EOC in HEU 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. 6 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.7 Normalized power distribution for present MCNPX model (Upper values) and reference [3] (Lower values) for EOC of first 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. 8 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
0.89 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. 9 Comparison between normalized power distribution for present MCNPX model (Upper values) and reference[3] (Lower values) for EOC of second 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.10 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.11 Comparison between normalized power distribution for present MCNPX model (Upper values) and reference[3] (Lower values) for EOC of third 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. 12 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. 13 Comparison between normalized power distribution for present MCNPX model (Upper values) and reference[3] (Lower values) for EOC of fourth mixed core.

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. 15 Power peaking for LEU at EOC.

4. CONCLUSION

— A computer model was designed to analyze the neutronic parameters during core HEU core and LEU core. The core multiplication factor illustrates good agreement in comparison with the reference results with maximum difference 500 pcm;

— Comparison of the calculated fuel burnup and Power distribution at both BOC and EOC for all core cycles shows average accuracy of 3%.

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