Burnup Calculations of TR-2 Research Reactor: MONTEBURNS Simulations and Experimental Verifications

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In this study, some neutronic calculations of first and second core cycles of 5 MW pool type TR-2 Research Reactor have been performed using Multi-Step Monte Carlo Burnup Code System MONTEBURNS and the results were compared with results from experiments and other codes. Time dependent k_{eff} distribution and burnup ratios belong to first and second core cycle of TR-2 Research Reactor were compared and consistence of the results were observed.

After modeling the first and second core cycle of TR-2 with MCNP5 Monte Carlo code, MCNP5 used in MONTEBURNS code has been parallelized in 8 HP ProLiant BL680C G5 systems with 4 quad-core Intel Xeon E7340 CPU, utilizing the MPI parallel protocol and simulations were performed on the 128 cores Linux parallel computing machine system. The results were obtained in a shorter time with parallelization of MONTEBURNS which uses MCNP in many steps.
KEYWORDS: MCNP5 Monte Carlo, Monteburns, Burnup, TR-2, Parallel Computing

I. Introduction

Burnup calculations of first and second core cycle of TR-2 Research reactor have been performed using MONTEBURNS code; the results were compared with the results from experiments[1)] and other codes (CNUREAS and reference calculations).

MONTEBURNS is a Monte Carlo burnup code that links the Monte Carlo transport code MCNP with the radioactive decay and burnup code ORIGEN2. MCNP calculates one-group cross-sections and fluxes that are used by ORIGEN2 in burnup calculations and provides criticality and neutron economy information if requested. After performing burnup calculations using ORIGEN2, MONTEBURNS passes isotopic compositions of materials back to MCNP to begin another burnup cycle. [2)]

A computer software system called Cekmece Nuclear Reactor System (CNUREAS) was developed in Cekmece Nuclear Research Center based on WIMS and CITATION nuclear codes that are widely used in the analysis and calculations of the nuclear reactor systems. WIMS produces material cross sections using cell model and CITATION uses these cross sections and computes neutron flux and fuel burnup.[3)]

II. Modeling of TR-2 Research Reactor

The TR-2 is a swimming pool type research reactor with a design power of 5 MW. It was established in Cekmece Nuclear Research and Training Center in 1981. Till now, thirteen core cycles have been operated in TR-2. High Enrich Uranium (HEU) and Low Enrich Uranium (LEU) fuels had been used in these core cycles. Only HEU fuels were used in TR-2 during first twelve core cycle. Both HEU and LEU fuels are MTR-type with 23 plates for standard element and 17 plates for control element.

First and second core cycle of TR-2 Research Reactor contained 10 standard and 4 control fuel elements. On one side, there were 4 Beryllium blocks as reflector and there were 2 Aluminum blocks at the corners of opposite site. [4)]

The beginning of first and second cycles core configurations of TR-2 Research Reactor are shown in **Figure 1** and **Figure 2**. In these figures, S1XX and C01X represent standard and control fuel elements respectively.

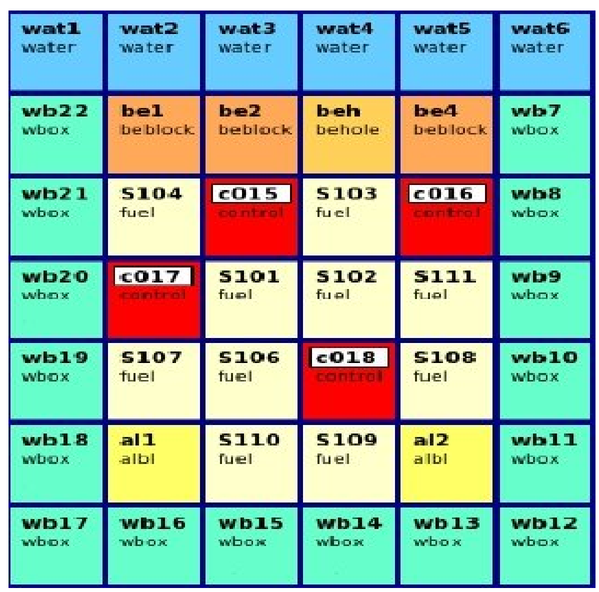

Fig. 1 Beginning of first cycle core configuration of TR-2

During the first and second core cycles, three dry irradiation facilities had been added to the core. At the beginning of second core cycle, a fresh fuel (S112) had been replaced with a spent fuel (S109).

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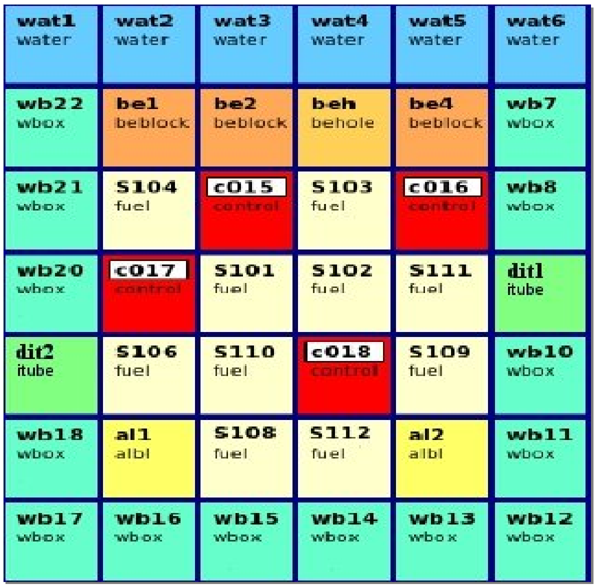

Fig. 2 Beginning of second core cycle configuration of TR-2

Time period of five sub-cycles of first and second core cycles is presented in **Table 1**.

Table 1 First and second core cycle time periods

Cycle 1	a	5.96 days	Startup
	b	14.92 days	First Irradiation Tube Insertion
	c	30.79 days	Second Irradiation Tube Insertion
Cycle 2	a	5.75 days	Fresh Fuel Loading
	b	33.33 days	Third Irradiation Tube Insertion

3D model of TR-2 Research Reactor was formed using MCNP5 is shown in Figure 2.

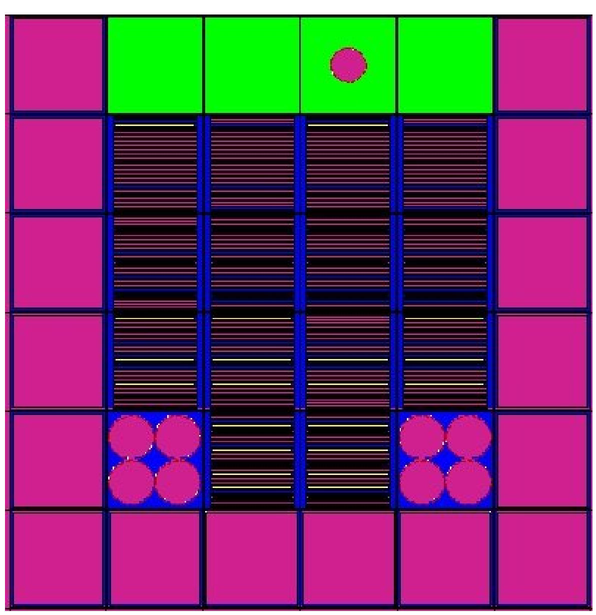

Fig. 2 MCNP5 model of TR-2 Research Reactor

III. Parallel Computing

MCNP5 used in MONTEBURNS code has been parallelized in eight HP ProLiant BL680C G5 systems utilizing the MPI parallel protocol and simulations were performed on the 128 cores Linux parallel computing machine system established in Turkish Atomic Energy Authority Information Technologies Unit. Technical specifications of this system are presented in **Table 2**.

Table 2 Technical Specifications of Parallel Computing System

Server	Specification
8 Blades	- Four 2.4 GHz Quad-core Intel Xeon 7330 processor - Total 32 GB DDR2 memory - Four 10/100/1000 Mbit/s Gigabit Ethernet - 4xDDR (20Gb) InfiniBand. - Red Hat Enterprise Linux Advanced Platform 5
1 Main	- 2.5 GHz Quad-core Intel Xeon 5420 processor - 4 GB DDR2 memory offload engine (TOE) - Two 10/100/1000 Mbit/s Gigabit Ethernet with TCP/IP

MONTEBURNS parallel computing results are presented in **Table 3** and **Figure 3**.

Table 3 Parallel Computing Results

Number of Core	Run Time (min)	Speed Up Factor
1	1604	1.0
10	187	8.6
20	94	17.1
30	72	22.3
35	63	25.5
40	61	26.3
50	58	27.7
70	57	28.1
90	60	26.7
110	64	25.1

The results were obtained in a shorter time as a factor of 28 with parallelization of MONTEBURNS. It is obviously seen that it is not effective to use more than 35 cores for this particular case that has total five million particles history.

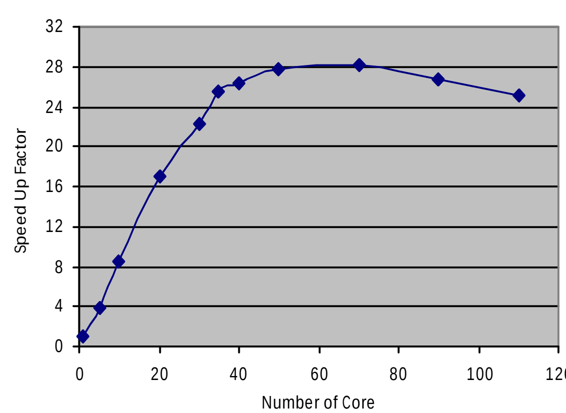

Fig. 3 Speed Factor of Parallel Computing

IV. Results

Time dependent k_{eff} distribution belongs to first and second core cycles of TR-2 Research Reactor is presented in **Figure 4**. In this figure, the MONTEBURNS result is given together with CNUREAS and reference calculations. During calculations, it is assumed that the reactor was continuously operated 24 hours a day for all core cycles.

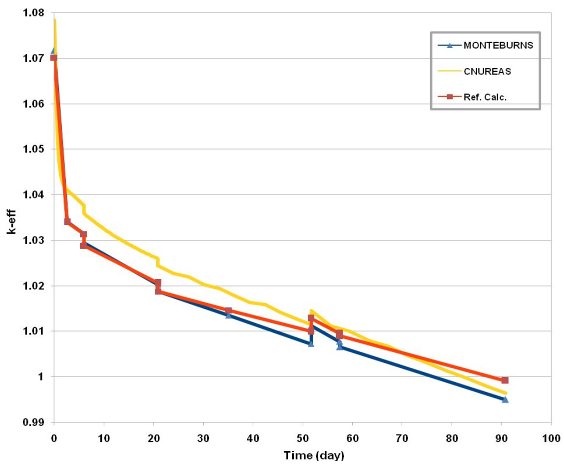

Fig. 4 k-eff distribution for first and second core cycles

Percentile burnup values presented in **Figure 5** and **Figure 6** are defined in Equation 1.

$$\text{Percentile Burnup (\%)} = 100 \times \left(1 - \frac{M^{i}_{235}}{M^{0}_{235}}\right) \qquad (1)$$

where M^{0}_{235} = U-235 weight of fresh fuel element

M^{i}_{235} = U-235 weight at the end of cycle i

11.20	13.70	12.90	11.40
10.80	13.45	12.58	11.05
10.96	12.92	12.27	11.01
11.53	14.48	13.07	11.91
11.80	13.20	13.10	11.00
11.53	13.29	12.93	10.44
11.87	12.73	12.53	10.47
12.28	13.74	12.33	10.40
11.00	10.20	12.50	9.95
10.80	10.09	11.53	9.73
10.74	10.33	12.08	10.24
10.38	10.52	9.21	9.26
CNUREAS	9.87	4.35	
Monteburns	9.38	4.05	
Ref. Calc.	10.13	4.53	
Ref. Exp.	10.01	4.14	

Fig. 5 Percentile burnup values of first core cycle

Percentile burnup values are calculated using MONTEBURNS at the end of first and second core cycle and they are presented in Figure 5 and Figure 6 together with CNUREAS, experimental and reference code results. Reference calculations had been made using GEREBUS diffusion code and were presented with experimental results in a technical report. [1)]

6.38	7.84	7.37	6.54
6.18	7.68	7.25	6.24
6.26	7.39	7.02	6.32
6.81	8.47	7.67	6.94
6.74	7.57	7.49	6.31
6.72	7.60	7.25	6.18
6.79	7.26	7.15	5.97
7.17	7.87	7.00	6.01
6.02	6.48	7.11	5.85
5.82	6.53	6.72	5.47
5.98	6.33	6.88	5.96
5.57	6.35	5.10	5.49
CNUREAS	5.28	5.50	
Monteburns	5.11	5.11	
Ref. Calc.	5.50	5.71	
Ref. Exp.	5.40	4.69	

Fig. 6 Percentile burnup values of second core cycle

Graphical presentations of percentile burnup values of TR-2 fuel elements at the end of first and second core cycles are given in **Figure 7** and **Figure 8**.

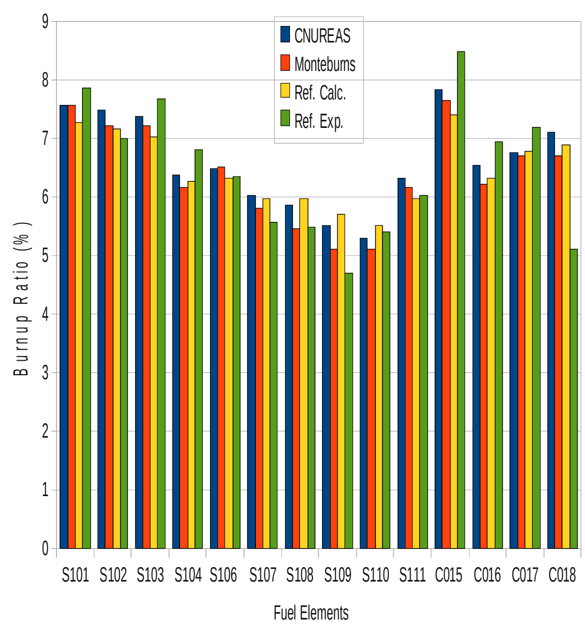

Fig. 7.Percentile burnup of fuel elements at the end of cycle 1

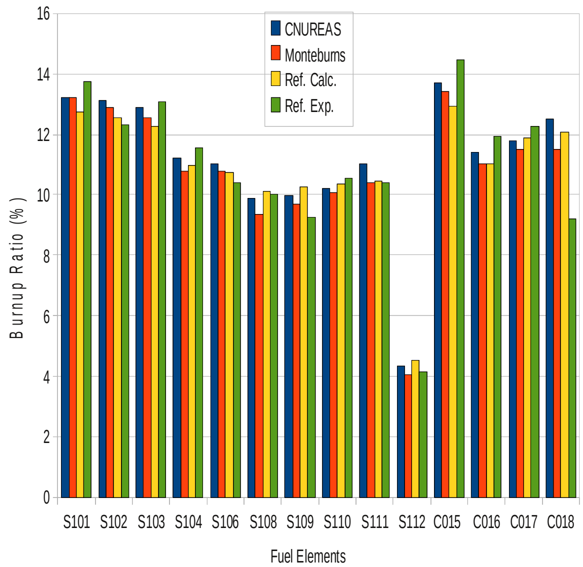

Fig. 8 Percentile Burnup of fuel elements at the end of cycle 2

V. Conclusion

When MONTEBURNS results are compared with CNUREAS, experimental and reference results, it is seen that time dependent k-eff distribution and percentile burnup values at the end of first and second cycles are consistence with each others. Some minor differences are observed between MONTEBURNS and reference results due to lack of cross-section set in ORIGEN2 library for TR-2 type research reactors that have MTR-type HEU fuels. Although the reactor had worked 8 hours in a day and 5 days in a week, it is assumed that the reactor was continuously operated 24 hours a day for all core cycles and all calculations (MONTEBURNS, CNUREAS and reference)

Long run time is a disadvantage of Monte Carlo codes such as MCNP. With parallel computing system, MONTEBURNS results have been obtained in a shorter time.

Acknowledgment

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