A Comparison of Equilibrium and Non-Equilibrium Cycle Methods for Na-Cooled ATW System

Y. Kim*, R. N. Hill, and T. A. Taiwo

Argonne National Laboratory
9700 S. Cass Avenue Argonne, Illinois 60439-4842, USA

1. Introduction

An equilibrium cycle method, embodied in the REBUS-3[1] code system, has generally been used in conventional fast reactor design activities. The equilibrium cycle method provides an efficient approach for modeling reactor system, compared to the more traditional non-equilibrium cycle fuel management calculation approach. Recently, the equilibrium analysis method has been utilized for designing Accelerator Transmutation of Waste (ATW)[2,3,4] cores, in which a scattered-reloading fuel management scheme is used. Compared with the conventional fast reactors, the ATW core is significantly different in several aspects since its main mission is to incinerate the transuranic (TRU) fuels. The high burnup non-fertile fuel has large variations in composition and reactivity during its lifetime. Furthermore, a relatively short cycle length is utilized in the ATW design to limit the potentially large reactivity swing over a cycle, and consequently 7 or 8-batch fuel management is usually assumed for a high fuel burnup. The validity of the equilibrium analysis method for the ATW core, therefore, needed to be verified. The main objective of this paper is to assess the validity of the equilibrium analysis method for a Na-cooled ATW core[4], which is an alternative core design of the ATW system under development.

2. Explicit Non-Equilibrium Analysis

The subcriticality of the Na-cooled ATW core is k_{src}=0.97 and the thermal power is 840 MWth. In this work, a half-year cycle length with a 135 Effective Full Power Day (EFPD) has been used and the discharged fuel is recycled after a 1-year cooling period. Detailed design specifications can be found in Ref. 4.

In the equilibrium analysis, one only needs to divide the core into several zones and to specify a batch size over a zone. However, in a non-equilibrium approach, the actual fuel management is applied in every fuel cycle, starting with the initial cycle. In this work, the core is partitioned into two TRU enrichment zones as shown in Fig. 1, and the enrichment ratio between the inner and outer zone is set to 1.31. The inner zone has the lower enrichments. This enrichment zoning is employed to reduce the ATW core power peaking factor, which generally appears close to the boundary between the core and the target/buffer. The specific batch indices used in this study are given in Fig. 1. Note that 7- and 7.5-batch are used for the inner and outer zones, respectively. The repeated discharge sequences adopted in this work are as follows:

Inner Zone: 1,2,3,4,5,6,7,1,,....
Outer Zone: (1-1,1-2),(2-1,2-2),(3-1,3-2),(4-1,4-2),(5-1,5-2),(6-1,6-2),(7-1,7-2),(8,1-2),(1-1,2-2),
(2-1,3-2),(3-1,4-2),(4-1,5-2),(5-1,6-2),(6-1,7-2),(7-1,8),(1-1,1-2),....

* Korea Atomic Energy Research Institute, Republic of Korea

The flux calculations were done with a 21-group diffusion theory model for a 1/6 ATW core with a rotational symmetry. Concerning the external spallation neutron source, a generic source distribution was assumed in the target zone.

3. Comparison of Equilibrium and Non-Equilibrium Analyses

Based on the fuel management scheme presented in the previous section, the explicit cycle-by-cycle analyses have been performed up to 100th cycle. Table I compares the two analysis results in terms of several important core parameters. The results of the equilibrium cycle analysis are taken from Ref. 4. For the explicit analysis, all the parameters were averaged over a 15-cycle period (from 86th to 100th cycle) to define a quasi-equilibrium state. From Table I, it is evident that the equilibrium analysis results match well with the explicit non-equilibrium analysis results. Also, it is clear that the two approaches provide very comparable fuel compositions, in spite of the noticeable differences in nuclides with small weight fractions. Concerning the power peaking, it is noteworthy that the equilibrium analysis method could also provide a reliable range of the peak power. Although the equilibrium analysis method does a good job from the viewpoint of the average parameters, it should be noted that it provides no information about the transition cycles.

4. Conclusions

From the average quantity point of view, results of the equilibrium cycle analysis method of REBUS-3 are quite comparable to those of the explicit non-equilibrium cycle analysis for the Na-cooled ATW core. It can be said that the equilibrium analysis could be a useful scoping calculation for a conceptual design of the ATW system. However, the results of an equilibrium cycle analysis should be carefully interpreted since there is no true equilibrium when a scattered reloading scheme is used for the fuel management.

References

1. B. J. Toppel, “A User’s Guide to the REBUS-3 Fuel Cycle Analysis Capability,” ANL-83-2, Argonne National Laboratory, 1983.
2. A Roadmap for Developing Accelerator Transmutation of Waste (ATW) Technology – A Report to Congress,” DOE/RW-0519, October 1999.
3. W. S. Yang and H. S. Khalil, “Blanket Design Studies of a Lead-Bismuth Eutectic-Cooled Accelerator Transmutation of Waste System,” Nuclear Technology, **135**, 162, 2001.
4. R. N. Hill et al., “Physics Studies of a Sodium Cooled ATW Design,” Proceedings of the IAEA Technical Committee Meeting on Core Physics and Engineering Aspects of Emerging Nuclear Energy Systems for Energy Generation and Transmutation, Argonne National Laboratory, Nov. 28-Dec. 1, 2000 (to be published).

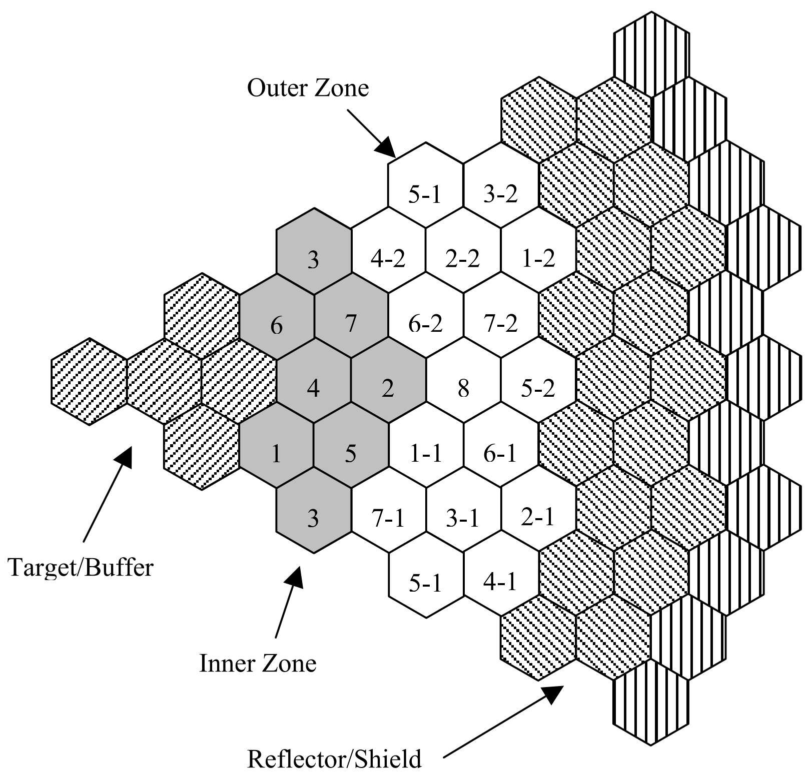

Fig. 1. Fuel management scheme for the non-equilibrium analysis

Table I. Comparison of ATW core parameters from equilibrium and non-equilibrium calculations

Parameter		Equilibrium	Non-Equilibrium
Fuel Particle Fraction (volume % in Zr-matrix)	Inner Zone	19.7	19.7
	Outer Zone	25.8	25.8
Multiplication Factor (k-src)	BOC	0.9700	0.9700
	EOC	0.9205	0.9203
Burnup Reactivity Loss (%Δk)		4.95	4.97
Core-Average Power Density (kW/*l*)		241	241
3-D Power Peaking Factor	BOC	1.85	1.83
	EOC	1.89	1.94
Peak Linear Power (W/cm)	BOC	376	372
	EOC	384	394
Discharge Burnup (a/o)	Average	28.3	28.3
Peak Fast Fluence (10^{23} n/cm^2)	Inner Zone	4.01	--
	Outer Zone	3.95	--
Net TRU Consumption Rate (kg/year)		233	233
Equilibrium Loading (kg/year)	LWR TRU	233	235
	Recycled TRU	590	586
	Total TRU	823	821
Heavy Metal Inventory (kg)	BOC	2627	2619
	EOC	2510	2502
Isotopic Composition of Feed Fuel (w/o)	U-234	0.47	0.50
	U-238	1.02	0.91
	Np-237	2.90	2.94
	Pu-238	5.04	5.21
	Pu-239	28.73	28.98
	Pu-240	31.49	32.10
	Pu-241	5.52	5.66
	Pu-242	10.56	10.20
	Am-241	6.85	6.65
	Am-243	3.40	3.20
	Cm-244	2.47	2.17
	Cm-245	0.71	0.59
	Cm-246	0.44	0.22