Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 29-30, 2008

TRU Deep-Burn in a Self-Cleaning Modular Helium Reactor (SC-MHR)

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1. Introduction

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The graphite-moderated modular helium reactor (MHR) is known to have capability of a TRU deep-burning (over 60% burnup) due to its unique features[1]. The objective of this work is to evaluate the TRU deep-burn in stand-alone MHR. The MHR is loaded with the standard UO2 fuel and self-generated TRUs are recycled into the same core, which is called self-cleaning MHR or SC-MHR. In Fig. 1, the fuel cycle concept of the SC-MHR is depicted. Spent fuel of the SC-MHR can be fed synergistically into fast reactors for a further transmutation or disposed of in a final repository.

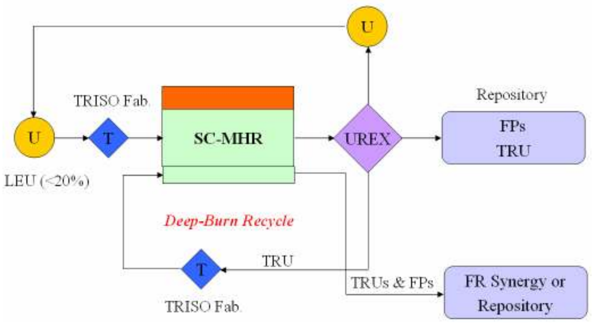

Fig. 1. Fuel cycle concept in SC-MHR.

2. SC-MHR Model and Methodologies

Figure 1 shows a 5-ring core model comprised of 144 fuel columns, which was derived the 3-ring GT-MHR[2]. Each fuel column is comprised of 9 fuel blocks. The fuel block design is identical to that of GT-MHR. The active core height is 7.93m and the core is reflected by 120cm-thick top/bottom graphite reflectors. The coolant inlet and outlet temperatures are 490°C and 850°C, respectively.

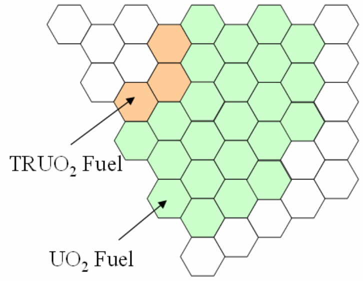

Fig. 2. Configuration of the SC-MHR core.

The fuel kernel is a UO_2 of a 12% uranium enrichment and the diameter of the kernel is 500μm. TRISO packing fraction is 26%. The coating thickness is as follows: 100μm for the buffer, 40μm for the inner and outer PyC, and 40μm for the SiC. In the SC-MHR fuel cycle, it is assumed that the spent UO_2 fuel is reprocessed with the conventional technology and the recovered TRUs are fabricated into the TRISO fuel after a 5-year cooling. In the case TRU fuel, a diluted kernel concept[1], instead of the conventional concentrated kernel, is used to maximize the TRU deep-burn. The kernel is comprised of 30 μm $TRUO_2$ fuel particles and carbon matrix. The diameter of TRU kernel is 300 μm and packing fraction of the TRISO particles is 35%.

An axial block shuffling scheme[1] in Fig. 3 is used for both uranium and TRU fuels. In the fuel shuffling, most-burned blocks are placed in the top/bottom regions to reduce the neutron leakage. The shuffling scheme is not optimized yet.

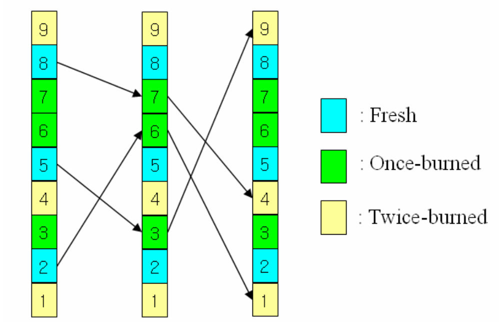

Fig. 3. Axial fuel shuffling scheme for SC-MHR.

The continuous Monte Carlo depletion code McCARD[3] is used for the analysis. The core performance is evaluated for an equilibrium cycle, which is obtained by cycle-wise depletion calculations.

3. Analysis Results

The SC-MHR has been analyzed with the McCARD code for a quasi-equilibrium cycle. Table I shows the composition of self-generated TRUs in SC-MHR. In Table I, The Cms isotopes are removed. It is observed that Pu-239 fraction is much smaller than that (~50%) in the typical TRU vector from LWRs.

In the SC-MHR, the equilibrium cycle length is 585 efpds (effective full power days) and the UO_2 fuel discharge burnup is 10.8%. In Table II, the deep-burn of TRU is summarized. The TRU discharge burnup is over 61%, which is considered extremely high since the fissile fraction of the TRU vector is only about 52. The deep-burning of TRU in SC-MHR is partly due to efficient conversion of Pu-240 to Pu-241, which is boosted by the uranium fuel in SC-MHR.

Table I. Composition of self-generated TRUs (no cooling)

Nuclides	Fraction, wt.%
Np-237	5.71
Pu-238	2.87
Pu-239	38.20
Pu-240	21.02
Pu-241	18.63
Pu-242	10.43
Am-241	1.13
Am-242m	0.056
Am-243	1.96

Table II. Burnup of TRU fuel in SC-MHR

Region	TRU mass, kg		Burnup, %	
	BOC	EOC	BOC	EOC
Fresh	50.3	31.5	0	37.3
1-burned	31.5	22.6	37.3	55.0
2-burned	22.6	19.5	55.0	61.2
Core	104.4	73.6		

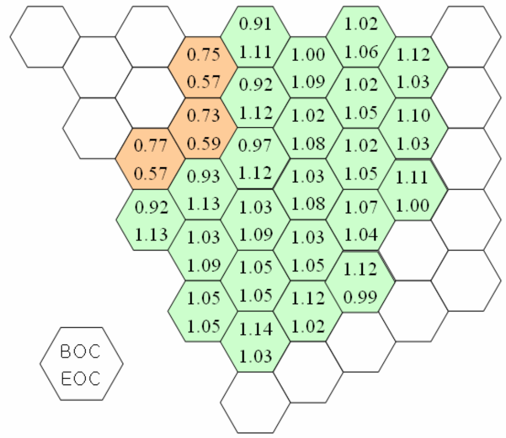

Fig. 4. Normalized power distribution at BOC and EOC.

Figure 4 shows the core radial power distribution at BOC and EOC. Clearly, power density of the TRU zone is significantly lower than that of the large uranium fuel region. The lower power density is ascribed to the deep-burning of the TRU fuel. Although a single UO_2 fuel was used in the whole uranium region, the power distribution in the UO_2 zone is rather flat. This is due to the presence of the TRU fuel between the inner reflector and uranium zone. Table III shows that transmutation of fissile isotopes Pu-239 and Pu-241 is extremely high. However, accumulation of the minor actinides is not avoidable in the SC-MHR core.

Table III. Composition of discharged TRUs

Nuclide	Fraction , %	Consumption, %
U-234	0.43	
U-235	0.07	
U-236	0.02	
Np-237	4.61	-70
Pu-238	14.58	+92
Pu-239	1.59	**-98**
Pu-240	5.37	-91
Pu-241	4.96	-86
Pu-242	41.67	+45
Am-241	0.53	-96
Am-242m	0.03	-81
Am-243	14.69	+183
Cm-242	0.40	
Cm-243	0.03	
Cm-244	10.42	
Cm-245	0.46	
Cm-246	0.15	

4. Conclusions

In the SC-MHR core, transmutation of self-generated TRUs is very effective. Although the fissile fraction in the self-generated TRU vector is much smaller than that of typical LWR TRUs, the TRU burnup is over 61%. Burnup of uranium fuel is also high, 10.8%, in the SC-MHR core. It is expected that the TRU deep-burn can be much higher if the fuel management and core designs are optimized.

References

1. Y. Kim and F. Francesco, “Optimization of TRU Deep-Burn in MHR,” ICAPP2007, 2007.
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3. H. J. Shim et al., “Numerical Experiment on Variance Biases and Monte Carlo Neutronic Analysis with Thermal Hydraulic Feedback,” Int. Conf. On Supercomputing in Nuclear Applications, SNA 2003, Sep. 22-24, 2003, Paris, France.

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