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Feasibility Study on TRU Deep-Burn with Inert Matrix Fuel in an MHR

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1. Introduction

This paper intends to evaluate the TRU deep-burn with an inert matrix fuel (IMF) in a Modular Helium cooled Reactor(MHR). The graphite-moderated MHR is known to have capability of a TRU deep-burning (over 60% burnup) due to its unique features[1]. In this work, the concept of inert matrix fuel (IMF) has been proposed for an efficient TRU deep-burn in an MHR. In IMF, TRU is diluted with neutronically inert matrices such as the oxides of zirconium, magnesium, and aluminum. The inert matrices of IMF are usually also chemically inert and have stability under geological formations, which provides a possibility of spent IMF direct disposal without reprocessing. A number of studies have investigated the IMF fuel performance in a LWR or a high temperature gas-cooled reactor[2-5]. In this work, an yttrium stabilized zirconium oxide (YSZ) is used as the inert matrix.

2. Core Model and Methodologies

Figure 1 shows a 5-ring core model comprised of 144 fuel columns, which was derived the 3-ring GT-MHR[5]. Each fuel column is comprised of 8 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.

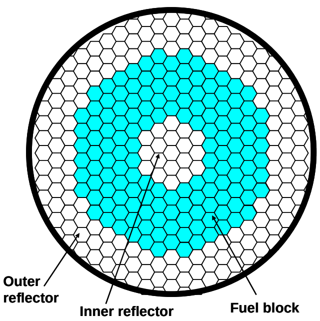

Fig. 1 Core Configuration of the 5-ring DB-MHR

The fuel kernel is an inert matrix fuel which is composed of TRU and YSZ matrix. The diameter of the kernel of IMF is 500μm. TRISO packing fraction is variable. The coating thickness is as follows: 120μm for the buffer, 35μm for the inner and 40μm for the SiC and outer PyC coatings.

For a comparison purpose, the conventional concentrated TRU is also considered in this work. In the case of concentrated kernel, the diameter of kernel is 200μm and the thickness of coatings is same as the IMF kernel.

An axial block shuffling scheme is used and a two-batch fuel management scheme is considered, as shown in Fig. 3. 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.

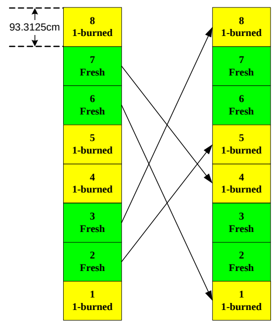

Fig. 3 Axial block shuffling in two-batch scheme.

The continuous Monte Carlo depletion code McCARD[7] 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

Regarding the TRU fuel, we calculated a TRU composition from LWR spent fuels by assuming a 50 GWd/tU burnup and a 5-yr cooling. The TRU compositions are given in Table I. It is assumed that Cm isotopes can be removed. In this work, a YSZ with 92w/o Y_2O_3 - 8w/o ZrO_2 was considered[2] and the kernel is comprised of 16 w/o TRU and 84w/o YSZ.

Table I. TRU Compositions (5-yr cooling)

Nuclides	Fraction, wt.%
Np-237	6.8
Pu-238	2.9
Pu-239	49.5
Pu-240	23.0
Pu-241	8.8
Pu-242	4.9
Am-241	2.8
Am-242m	0.02
Am-243	1.4

The packing fraction of the TRISO in the concentrated TRU fuel compact is 18% while it is 27.5% for the IMF fuel. In the 2-batch fuel management scheme, the cycle length is 540 EFPDs in the concentrated TRU case, while it is 390 EFPDs in the IMF case.

Table II. Burnup of TRU fuel (1/6 Core)

Fuel		TRU mass, kg		Burnup, %	
		BOC	EOC	BOC	EOC
Concentrated TRU Core	Fresh	101.6	64.4	0.0	36.6%
	1-burned	64.2	47.4	36.8%	53.3%
	Core	165.8	111.8		
IMF TRU Core	Fresh	69.6	42.8	0.0	38.5%
	1-burned	42.7	30.6	38.7%	56.1%
	Core	112.4	73.4		

Table III. TRU Compositions Before and After DB (Concentrated TRU Core, 1/6 Core)

Nuclide	Charge		Discharge		
	Mass (kg)	Fraction (%)	Mass (kg)	Fraction (%)	Consumption (%)
U234			0.10	0.21	
U235			0.01	0.03	
U236			0.006	0.01	
Np237	6.9	6.8	3.45	7.3	-50.2
Pu238	2.9	2.9	6.12	12.92	111.3
Pu239	50.3	49.5	2.54	5.35	-95.0
Pu240	23.4	23.0	9.42	19.87	-59.7
Pu241	8.9	8.8	8.92	18.81	-0.1
Pu242	4.9	4.9	10.33	21.78	109.4
Am241	2.8	2.8	0.90	1.90	-68.2
Am242m	0.02	0.02	0.04	0.09	122.7
Am243	1.40	1.4	3.13	6.60	123.5
Cm242			0.41	0.86	
Cm243			0.02	0.03	
Cm244			1.83	3.87	
Cm245			0.16	0.33	
Cm246			0.018	0.04	
Pu	90.4	89.0	37.3	78.7	-58.7
TRU	101.6	100.0	47.41	100.00	-53.3

Table IV. TRU Compositions Before and After DB (IMF TRU Core, 1/6 Core)

Nuclide	Charge		Discharge		
	Mass (kg)	Fraction (%)	Mass (kg)	Fraction (%)	Consumption (%)
U234			0.05	0.16	
U235			0.01	0.02	
U236			0.003	0.01	
Np237	4.8	6.9	2.55	8.3	-46.9
Pu238	2.0	2.9	3.93	12.86	96.8
Pu239	34.5	49.6	1.32	4.30	-96.2
Pu240	16.0	23.0	4.99	16.32	-68.8
Pu241	6.1	8.7	5.56	18.17	-8.6
Pu242	3.3	4.8	7.92	25.89	136.7
Am241	1.9	2.8	0.47	1.55	-75.5
Am242m	0.01	0.02	0.02	0.07	64.3
Am243	0.95	1.4	2.23	7.29	135.4
Cm242			0.34	1.11	
Cm243			0.01	0.04	
Cm244			1.10	3.60	
Cm245			0.07	0.23	
Cm246			0.009	0.03	
Pu	61.9	88.9	23.7	77.5	-61.7
TRU	69.6	100.0	30.58	100.00	-56.1

The results are summarized in Tables II, III and IV. From Table II, the discharge burnup of the IMF TRU fuel is significantly higher than that of the concentrated TRU fuel. Tables III and IV indicate that the transmutation rate of the fissile isotope Pu239 is extremely high and higher with the IMF fuel. Also, the results show that the fissile isotope Pu241 is transmuted in the IMF core, but it is accumulated in the concentrated TRU core.

4. Conclusions

In this paper, an yttrium-stabilized-zirconium inert matrix fuel has been introduced for deep-burning of TRUs in an MHR core. From the results, it is shown that the IMF fuel is more effective than the conventional concentrated TRU fuel. It is expected that more effective TRU deep-burn can be achieved in the IMF fuel concept if kernel packing fraction and batch sizes are optimized.

Acknowledgements

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